Illustrating Primary Science: A teacher's use of representations

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Abstract

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Many topics in the current science curriculum pose difficulties for teachers in that they are too complex to allow children to experience at first hand, due their size or hazardous character. In such cases representations are commonly used. Teachers select representations for use in their lessons and the extent to which such representations contribute to teaching and learning in the classroom has important implications for the construction of knowledge in the primary science classroom.

The theoretical framework for the study arises from a social constructivist perspective which proposes that children hold mental models of scientific phenomena, and that learning takes place when these models are challenged sufficiently to effect conceptual change, leading to increased knowledge and coherent understanding.

A participant observer and insider perspective was taken within a case study approach of a teacher using representations in series of Year 5 (ages 9-10 years) science lessons on the Earth in Space. Data were captured by video recording to observe incidents and aspects of the teacher's use of representations.

An analysis of the video recordings was made to note all the aspects observed which included gestures employed to highlight and/or add information about the phenomena depicted and all verbal emphases and additions. In addition, a combination of two analysis systems was used to establish informational content of the representations themselves, and of the verbal and gestural teacher additions. One grid allowed the combination of illustration and text to be assessed for informational content and the second grid enabled attributes of the phenomena to be determined. This allowed conclusions to be drawn about the manner of use of representational material in relation to informational content and cognitive suitability for learning.

Declaration

The work presented in this thesis is my own work.

Gwyneth A. Marsh

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Chapter 1

Introduction to the study

1.1 Background

This study investigates the way a primary science teacher used representations in a series of science lessons on the National Curriculum topic of the Earth in Space (DES 1989) (now the Earth and Beyond, DfES 2005). The initial grain of an idea for this study originated from personal experience as a teacher in many teaching situations, noting the responses of children to representational material I had selected to use with them in the classroom. The idea grew and developed into the detailed research study set out in this thesis.

1.2 Setting the scene

Primary school teachers generally use a variety of materials to illustrate their lessons. The range of materials to choose from is vast, from drawings and photographs in books and on wall posters, video recorded material and, most recently, computer programs and CD-ROMs, enabling almost every aspect of the curriculum to be viewed. In England and Wales the National Curriculum lays out the content of all subjects taught in primary schools (DfES 2005). In the science curriculum many topics lend themselves to the use of illustrative materials, for example the Earth in Space topic involves the study of objects, structures and behaviours of systems which, whilst their effects are experienced in our everyday lives, the actual mechanisms of operation cannot be directly observed. In this way representational materials provide an opportunity to view the normally inaccessible.

Visual imagery dominates contemporary society in every aspect of our lives. Adults are accustomed to looking for visual clues to navigate their world and are proficient readers of the plethora of images in their surroundings. Many images convey necessary information; other images manipulate our senses in an attempt to promote products. Television images, news reports, documentaries or fictional narratives supply information and entertainment. These images are presented in such a way that the lines of distinction between fact and fiction can often be blurred (Mirzoeff 1999).

The images surrounding us in our daily lives are carefully constructed to convey a particular meaning, the way out of a building, the desirability of a particular brand or product, the sequence of events in a news story. Meaning may be embedded in these images on different levels depending on the devices the makers of the images have used. Devices such as metaphors and/or analogies included in their construction and the intended meaning of the image makers contribute to the meaning intentionally embedded in the final image. Barthes (2000) highlighted the significance of the content of images, using ideas from Saussure and semiotics, by viewing representations as sign-systems. He 'deconstructed' a number of contemporary representations to look for signs and signifiers relating to the depiction of everyday life which were coded to imply societal messages. Such images, constructed with the intention of being viewed, could therefore be seen as having meaning embedded in them.

Reading images, therefore, can be a complex activity and depending on the intricacies of composition, meaning can be open to differing interpretations. Individuals seeing an image for the first time interpret it through the lens of their experience, adding increased potential for misinterpretation, depending on their level of previous experiences (Sturken and Cartwright 2003). In the case of advertisements, for example, the inclusion of, say, the flying lady statue, usually found on the bonnet of a Rolls Royce car, could imply affluence, but only for those who are culturally aware that the statue is normally found on a very expensive car. Without this knowledge, the meaning constructed from viewing the image will not be that intended by the makers of the image and therefore a misinterpretation of what was intended. The interpretation of an image is therefore culturally and experientially dependent (Mirzoeff 1999, Sturken and Cartwright 2003). Children have relatively limited experiences of both viewing and interpreting images and cultural knowledge in comparison with adults, so their interpretation of the same images may be different. They bring all their visual experiences into the classroom.

Teachers preparing illustrative material for lessons have an enormous variety of images from which to select. Increasingly these images are photographs or are brightly coloured illustrations and diagrams with varying amounts of textual accompaniments. Photographs may imply accuracy of information (Winston 1998, Emmison and Smith 2000, Rose 2001, Sturken and Cartwright 2003). Diagrams, whilst not perceived as having the same level of accuracy as photographic images, may contain information impossible to convey in a photographic image (Tversky *et al.* 2000). Textual additions can complement both photographs and diagrams if appropriately positioned (Hartley 1994, Mayer *et al.* 1996,). The addition of textual material to moving images such as video clips or computer animations can either be spoken or written, but in either case has the potential to complement visual images. Conversely, accompanying textual material, either written or spoken, can confuse and detract from visual information if placed inappropriately (Mayer *et al.* 1996). Therefore, selecting appropriate material to illustrate particular scientific phenomena has to take into account many factors other than the phenomena themselves. The type of representational material selected will have implications for teaching and learning in the science classroom.

Teaching in England has undergone radical changes in recent years. In England and Wales, the advent of the National Curriculum, initially in 1989, and its subsequent and continuing revisions, has increasingly placed focus on teaching from the child's perspective, encouraging personal construction of knowledge (DfES 2005). This focus on thinking and reasoning as important aspects of learning has deeply historical roots in philosophy, which seem to have been overshadowed during the pedagogical developments of the 20th century. The philosophical provenance of contemporary theories of teaching and learning gives depth and resonance. The emphasis on learning from the children's perspective implies that the knowledge and experience children bring to the classroom is valuable and related to their future learning.

The notion that ideas children bring to the science classroom affect their capacity for thinking about and learning new knowledge has for many years predominated in science education (Gilbert *et al.* 1982, Gilbert and Watts 1983, Driver *et al.* 1994). The emergence of a constructivist theory of learning, which posits children constructing new knowledge from the roots of their experiences, encourages the restructuring of these personal ideas. Constructivism has its roots in philosophy, where debates about intuitive and learned knowledge have continued for hundreds of years.

The methods teachers use to incorporate children's ideas into their pedagogy to ensure effective and continual development of thinking and learning have also been under scrutiny. Contemporary theories of teaching and learning have their roots in psychology, a discipline which emerged from philosophical debates regarding thinking, learning and the acquisition of knowledge. It is worth considering these origins and their contribution to contemporary pedagogy in order to understand the implications arising from the contributions made from numerous disciplines involved in the debate. Holistic teaching and learning methods, currently promoted by government, consider all aspects of the human condition and the factors affecting it. Understanding the historical roots of contemporary notions of teaching and learning may be helpful in informing classroom practices especially those involving the use of representations.

Illustrative materials for teachers have been developed in every media format, so that it is now possible to experience any given phenomenon in a number of ways. Whichever visual media are used to illustrate phenomena, the representations have to be viewed. The understanding of visual perception has its origins in psychology, where theories of how images are viewed and interpreted were developed. These theories evolved from the early philosophical debates about what actually constitutes sensory experience and its relationship with and to knowledge acquisition.

The different types of representation, 2-dimensional, 3-dimensional and animated sequences present different viewing experiences due to their different formats of presentation. The different modes of representation may, therefore, present different opportunities for knowledge construction, depending on the manner in which the different modes of representation are used in a teaching sequence.

The way teachers organise their lessons and the techniques they use to engage children in learning provide the context for children's learning. Pedagogy is determined by theories of teaching and learning and a teacher's understanding of the relevance of these theories to their own practice. Teachers' knowledge and experience of how children learn will inform the style of teaching they adopt in their classroom. Government educational policies, required curricula and the ethos prevalent in the school will also contribute pedagogical practices. The representational materials teachers use within this context to support their pedagogical practice is an integral part of the process of teaching and learning in the primary science classroom.

1.3 Personal motivation

The original idea for the study arose directly from the classroom, where, working with a class of Year 5 (age 9-10 years) children on an Earth in Space topic (DES 1989), I had used three different representations of the Solar System. Rather than reinforcing their knowledge of the structure of the Solar System as had been my intention, the representations raised questions. Discussing these questions with the children revealed that the representations appeared to have encouraged the formation of alternative ideas about the structure of the Solar System.

The potential for misinterpretation of visual materials was further reinforced by another classroom experience where slides of animals expected to be found in a rainforest were shown to the class. The slides gave no indication of size or scale. One slide in particular showed what appeared to be a brightly coloured woodlouse and I had assumed that they would be small, based on my knowledge of these animals, but when we found them in their natural habitat the reality proved to be very different, they were enormous.

A change in my pedagogical practice, presenting classes with numerous alternative representations of the same phenomena, resulted in lively debates, as differing interpretations of the illustrative materials were proffered by the children, prompting my consideration of the intended meaning of representations and the effect this had on constructing meaning from them. The notion that a viewer may read the informational content of a representation within the context of their own experiences and the context in which it is being viewed, consequently constructing their own meaning and therefore potentially a new interpretation, began to emerge.

A serendipitous encounter at my first Association for Science Education local meeting resulted in an opportunity to develop my interest through a 'teachers as researchers' group, and eventually led to this study.

The journey from that first introduction to higher degree research work with children has changed the way I view the world, both on a personal and professional level. It has consolidated and explained ideas that had been developing over my many years in the teaching profession, and given new insights into children's learning and teachers' pedagogical practices, resulting in a deeper personal understanding of processes of teaching and learning and their consequences.

In the primary classroom, where the same teacher teaches most of the curriculum, there is a unique opportunity for building close relationships with the children affording a deeper understanding of individual children and their learning. Conducting research studies with pupils with whom this close relationship has been built allows a particular insight into the activities that occur during lessons. Though I was not at the time of the study actually teaching in the school, I was invited to work in the classroom of a colleague with whom I had previously worked and with children I had previously taught. Consequently I had built up a close relationship with both the teacher, through shared science teaching, and the children, through class teaching and a residential field trip. In this situation I had a rare opportunity to conduct research in familiar surroundings, with familiar children and a familiar adult. The study therefore represents a naturalistic inquiry into a science classroom, with myself as a participant observer and with an insider perspective.

My personal philosophy for teaching had for many years been that of a teacher as a facilitator, to some extent working at odds with the ethos of the schools I taught in. The ideas and responses of children in the classes I taught contributed to the lessons I planned. The materials I used in my lessons were carefully selected within the limitations of availability and my perceived adequacy for purpose, to give the children experiences and examples of the phenomena we were studying. I had expected these representational materials to contribute to conceptual development, which they did but not always in the way I had anticipated. This led to the notion that the representations themselves were having an effect on the potential knowledge construction opportunities they afforded the children. What this effect might be and the factors contributing to any effect is summarised by the hypothesis discussed below.

1.4 Formulation of the hypothesis

The initial notion of the significance of materials teachers use to illustrate lessons began to crystallize as a result of a small scale teacher researcher project undertaken with my then current class of children, discussion with colleagues in different schools and the support of a teacher researcher group (MISTRE)[1]. This gave me the opportunity to conduct research as a practitioner researcher with the classes I was currently teaching. During an investigation into the relative sizes, distances and movements of the planets in the Solar System, it became apparent that the children were interpreting and creating meaning from the representational material available to them in a way I had not anticipated. This was reinforced by a later study into children observing a representation of the human body in the Millennium Dome (Marsh 2001). It became clear that the visual representations were not necessarily fulfilling the purpose for which they were intended. This led to another study looking at a number of representations of the same phenomena, this time as presented in books, to investigate what children saw when they looked at the different representations. The results of this study indicated that there were factors contributing to the meaning constructed by the children viewing representational material which may not have been considered by the image constructors. To this end I began to use a variety of different representations of the same phenomena in my teaching and observed the children forming their various interpretations. There appeared to be beneficial effects to using different materials illustrating the same phenomena during teaching sessions. The main effect appeared to be the stimulation of discussion, where children who saw different aspects in the materials subsequently questioned the validity of the other interpretations (Marsh 1997b). The hypothesis began to form around the variety of representations available to facilitate children's learning and the importance of the selection of representational material and the way in which these materials were used in lessons.

A growing personal awareness of mental models and their implication for teaching and learning suggested that children's different interpretations of the material I presented them with could in fact be an expression of their model of the phenomena. They were interpreting what they saw in terms of their own understanding at that time.

In order for appropriate questions to be formulated for a larger study an hypothesis was proposed to encompass the notions arising from the small scale studies. These small scale studies had highlighted a number of factors which may be significant in the use of representational material in the science classroom. These factors were individually considered and their potential effect incorporated into the hypothesis to prompt a survey

[1] Models in Science and Technology Research in Education

of the relevant literature from which general questions relating to the significance of these factors were derived.

The hypothesis is:

Teachers use a variety of representations to facilitate learning for children of many phenomena in primary science education. The selection of these representations is dependent on the following factors:

1. *The teacher's own knowledge of the phenomenon.*
2. *The knowledge that the teacher feels that the children need to understand.*
3. *The teacher's view of how learning takes place.*
4. *The availability of resources.*

The way in which the representations are presented and used during lessons may influence the way children understand the phenomenon being studied.

In addition, the way in which representations are interpreted by both teachers and learners may influence their efficacy as tools for teaching and learning.

Three main themes emerged during the formulation of the hypothesis which determined the paradigm within which the study was conducted.

1. Teachers' understanding of how children learn and their resulting pedagogy.
2. The types of representational material used in lessons and how it is used.
3. The way in which representational material might contribute to learning – how it might be interpreted by all those who looked at and interact with it.

The literature review which is outlined below explored these issues and gave rise to the questions which the study is designed to answer in a specific form. The themes initially gave rise to three general research questions:

1. *What type of representations do primary science teachers select?*
2. *How are these representations used in lessons?*
3. *Do the representational material present a cognitively coherent pathway to facilitate the construction of knowledge by the pupils?*

The specific study was designed to focus on the use of representations by one teacher in a series of science lessons so that the use made of representational material could be observed over the whole period of the lessons. The methodology needed to take into account the classroom situation for both the teacher and children included in the study and myself as the researcher. The design and methodology of the study were to an extent determined by the underlying premise from which I personally worked as a teacher and the classroom situation I knew I would encounter. These issues will be discussed in detail in the following chapters.

The general research questions were therefore extended to address the specific study of a single teacher in a primary science classroom, teaching a complete series of lessons about the Earth in Space. Observing a whole series of lessons would give an overview of the use of representational material as the topic progressed and extend the enquiry from a single instance to enable any development of use of representational materials to be noted. Therefore the research questions, specific to the setting of this study are:

1a) What type of representations were selected by the teacher?
1b) What criteria were used for selection?

Sections 2.3, 2.4, 2.6, 2.7, 2.9, and 2.10 in Chapter 2 provide background literature to support these questions.

2a) How were representations introduced to the class?
2b) How much use was made of representations?
2c) Were representations used in combination?
2d) Were representations used in context?
2e) Were the representations 'fit for purpose' with appropriate informational content?
2f) Were the same representations used repeatedly?
2g) Were the same representations used for different targets?

The literature pertinent to support these questions is addressed in Chapter 2, Sections 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, and 2.10.

3a) What was the teacher's understanding of how learning takes place?

3b) Was the teacher aware of any potential misunderstandings the children might hold about the topic?

3c) Did the representations address the commonly held misconceptions of the topic?

3d) Was the informational content of the representations sufficient for engendering knowledge construction and conceptual change in understanding?

The literature informing these questions is addressed in Chapter 2, Sections 2.4, 2.5, 2.7, 2.8, and 2.10.

1.5 Overview of the thesis

Chapter 2 reviews the literature to address the themes identified by the research questions, namely teaching and learning science, mental models and misconceptions, representational material and how it is perceived.

Initially the changing views of learning in the classroom are reviewed, to set the pedagogical context for the research questions. An important aspect of pedagogy in the science classroom is that of models and modelling, and this raises issues about the nature of representations and the way they are interpreted, with particular reference to primary science.

Visual perception, upon which learning with representational material depends, is then considered to raise general questions on the place of representational material in the science classroom.

The research on different types of such representations and their interpretation in the context of the science classroom is then reviewed, with particular reference to textbooks.

The literature review chapter concludes with a discussion to consider curriculum constraints for primary science teacher training and teaching to determine the content knowledge required to teach the topic, and a review of the common misunderstandings which occur in the Earth in Space, the particular topic chosen for this study.

The design of the study is described in Chapter 3, which also considers the methods selected for observing the type and use a single teacher made of representations from the perspective of a teacher researcher, inside the classroom. The selection of the study group and the topic of the lessons are outlined and described. The techniques used to collect the data to answer the questions are discussed and the choice of particular methods is explained to justify the reasons for their selection. The pros and cons of these methods are considered in terms of the constraints imposed by the school situation, participant selection and relevant data required to answer the research questions.

In order to assess the informational content of the representations used, various methods of analysing images were considered as tools for determining what information was available in images for viewers and from which meaning could be construed. The actual methods used for analysis of images in this study are considered in detail in Chapter 4 together with the reasons for the selection of these methods over other available methods are discussed.

The results of the study are presented in Chapter 5 and the conclusions drawn from these results in Chapter 6. A discussion follows in Chapter 6 to show how the research questions have been answered and to examine the issues raised by the results concerning the use of representations in the primary science classroom.

The overall findings of the study are placed in the context of current educational practices and the implications for the use of illustrative materials in science lessons in particular are discussed in Chapter 7. The contribution to knowledge, proposals and suggestions for further development of issues arising from this study are also considered in this chapter.

Material, in the form of figures and tables, is included in the body of the thesis where it is relevant. The appendices contain additional material, not considered germane for inclusion in the text but which provides background information supporting the methods and analysis of the data.

Chapter 2

Learning Science with Representational Materials in the Primary Classroom

2.1 Introduction

This chapter introduces the literature considered relevant to the background of the themes identified in the hypothesis described in the previous chapter. The themes are outlined and discussed in detail in the following sections of this chapter and lead to a set of general research questions which are then made specific in the context of the teacher researched in Chapter 3.

2.2 The structure of this chapter

Teachers develop their own styles and practices of teaching, within the limits and constraints of their individual schools, classrooms, groups of children and their understanding of how learning occurs, together with influences from their teacher training background. Of these approaches to teaching, knowledge construction by individual learners, constructivism, is currently strongly promoted as an effective pedagogy for teaching science in classrooms in England (Millar and Osborne 1998).

Constructivist principles of teaching and learning emerged from years of debate and research about the nature of knowledge, as reviewed in Section 2.3. The philosophical basis of the development of constructivism also has relevance to the development of knowledge acquisition theories in psychology and their subsequent inclusion in practices of teaching and learning. Arising out of changing notions of effective teaching and learning approaches is the importance of the knowledge children and teachers take into the classroom. This prior knowledge constitutes their personal mental models of not only the school and classroom situation and the expectations of what is likely to occur there but also their interpretation of any new knowledge presented in that setting.

Mental models form the starting point for constructivist practices in learning science for both teachers and learners. These ideas will be expanded in Sections 2.4 with particular reference to the development of model-based teaching and learning and the relevance of mental models and expressed models to visual material.

Visual materials used in the science classroom can take a variety of forms, 2-dimensional images, 3-dimensional models or animated sequences, for example. Each of these modes of visual material needs to be interpreted by the viewer in order to be cognitively available for the construction of meaning. Interpretation of visual material is initially at a perceptual level, as discussed in Section 2.5. Perception, understanding how we sense, respond and interact with our environment, is an area of study which developed from early theories of knowledge acquisition. The precise mechanisms of seeing are examined to explain how visual materials might be interpreted. This leads into the way in which images used in science teaching may be created to facilitate the construction on knowledge.

In Section 2.6 consideration is given to the selection of appropriate representations intended to present a mental model of a scientific phenomenon or to challenge a potential misconception.

Visual forms of representational materials are used in science classrooms for a variety of reasons, one being the inaccessibility of the real objects or events. Different forms of commonly used representation are examined in Section 2.7 in terms of their use as tools for teaching and learning, with particular attention given to the considerable range of representations in textbooks.

The content knowledge required by teachers to teach the Earth in Space topic, which provided the context for the classroom research undertaken, is discussed in Section 2.8 in terms of the National Curriculum for Science. The level of scientific knowledge required to understand the processes of events, such as the occurrence of day and night, the phases of the Moon and seasonal change, is relatively advanced. However, these are phenomena experienced at first hand, resulting in the occurrence of personal explanations of these events, which may not concur with the current scientific explanations but have been found to be held across communities.

Because of the prevalence and relevance to the study of commonly held misunderstandings about the Earth in Space, these are explained in Section 2.9 and mediating principles highlighted.

Section 2.3 discusses teaching and learning and relates these notions to the significance of teachers' pedagogical practices for knowledge construction in the primary classroom.

2.3 Learning in science

2.3.1 Background to current ideas of learning in science

Teaching and learning have undergone major changes with the emphasis of 'responsibility for learning' shifting from being solely that of the teacher to a shared undertaking with children with the teacher as a facilitator rather than an instructor. Science education, in particular, has been the subject of many detailed research studies into the way children learn science, the ideas they bring to lessons and the most effective methods for enabling learning (Driver *et al.* 1994, Fensham 1995, Blown and Bryce 2006). The continued progression of knowledge and understanding of how learning occurs through developments in cognitive psychology informs pedagogy (Osborne and Wittrock 1985, Driver and Bell 1986). Understanding the way children interpret the world they experience has led to acknowledgement of children's ideas about scientific phenomena as integral to any subsequent learning situation (Driver *et al.* 1994, Osborne *et al.* 1994).

Theories about the nature of scientific knowledge and the way children learn this knowledge have been augmented by research initially motivated by the decline in interest and uptake of science by secondary school pupils in the 1950s and 60s (CACE 1967, Sharp 2004). The Nuffield Co-ordinated science scheme started the movement towards more practical-based science curricula, a movement which continued to develop through the 70 and 80s. The implementation of the National Curriculum in 1989 with its clearly defined programmes of study for all school subjects stimulated further research into the nature of children's understanding of the scientific phenomena stipulated for study. This research uncovered a wealth of information about the nature of scientific concepts held by both children and adults (Osborne *et al.* 1994, Vosniadou and Brewer 1994).

The realisation that children brought to their science lessons plausible, but different, explanations for the science topics they were required to study further fuelled the debate about the nature of knowledge and how it was effectively acquired and assimilated and the role of teachers in this process (Gilbert *et al.* 1982, Driver and Erickson 1983, Driver and Bell 1986).

These factors all have important implications for the current emphasis of constructivist pedagogy, promoted by government and teacher training establishments, as an ideal in schools and science classrooms in particular (Millar and Osborne 1998, DfES 2005).

Contemporary teaching methods have resulted from ancient epistemological and ontological theories of knowledge acquisition (Harlen 1998, Millar and Osborne 1998, DfES 2005). The concept of a constructivist philosophy has its basis in classical antiquity (Osborne and Wittrock 1985). This has been integrated into the constructivist position in the form of Socratic questioning, where opened-ended, challenging questions are asked of children in order to promote debate about their ideas (Driver *et al.* 1993). Guidance in the form of challenges to thinking and reasoning, through discussion and activities, facilitates learning. Introducing conceptual conflict where ideas are expressed as a result of questioning, and can be compared with others' ideas, opens an arena where differences can be debated and discussed to reach consensual agreement and a move towards explanations agreed by the scientific community (Driver and Erickson 1983, Driver *et al.* 1994).

2.3.2 Learning as a social activity

For many years the majority of investigation into learning and knowledge acquisition was conducted with animals and adults. Findings were extrapolated and applied to children and put into practice in schools. Jean Piaget (1896-1980) was one of the first investigators to suggest that knowledge acquisition in children may be different from that in adults. He introduced the term 'schema' to mean a fluid mental structure which could be altered by assimilation and/or accommodation of new material, which consequently resulted in learning. The scope for the development of schemas was, he suggested, dependent on the child's level of cognitive development, which in turn was dependant on age. This stage theory of intellectual development had important and far reaching influences on theories of teaching and learning, for children as learners in their own right, and was to be radically influential in schools and result in changes in government policies on education. Piaget's stage theory of intellectual development as an age-determined progression suggested that all aspects of development might therefore be age-related. This implied that there were specific developments within the brain occurring as a result of maturation in conjunction with experiences.

The notion of child-centred learning, where cognitive development was critical to the capacity to learn new knowledge, was also being investigated by Lev Vygotsky and Alexander Luria in the United States of Soviet Russia. Vygotsky (1896 - 1934) also suggested schemas as 'building blocks' for learning, but these building blocks were not sufficient in themselves. He proposed that knowledge was socially constructed and dependent on the exchange of ideas; to this end he suggested that language was important for the development of schemas. He acknowledged that children had their own ideas and through discussion with others these ideas could be made explicit and compared. Learning occurred as schemas are enlarged and developed through the social activity of discussion. In the case of children, discussion was to be carefully framed to enable them to move from known facts, their initial schema, to considering unknown facts, which could then be incorporated into the schema. This area between the known and the attainable new he called the 'zone of proximinal development' (ZPD). In order for adults, or a 'knowledgeable other', to assist children to move through this zone an awareness of the child's knowledge at that time was necessary. Then, with support and facilitated discussion, the child would be confident to move, through their own efforts, towards the new knowledge, incorporating it onto their existing knowledge (Vygotsky 1962).

Though Vygotsky did not use the term scaffolding it has become associated with his name, since Bruner suggested the term to describe the journey through the ZPD, a way of explaining how new knowledge was built on the framework of previous knowledge (Jarvis 2005). For children to make this move independently was an important feature of Vygotsky's theory. He felt it enabled the learner to be in control of the rate and progression of the construction of new knowledge. Knowledge constructed in this way, was, he felt more durable and transferable (Vygotsky 1962). Vygotsky was working at the same time as Piaget but the political climate between Britain and Russia was not conducive to the sharing of ideas. Consequently his ideas were not incorporated into the developing Western theories of teaching and learning until much later.

Schemas, later termed concepts, were seen as groups or categories, each group sharing similar characteristics. Any new experience was initially assigned to a category and over time these categories developed and expanded to accommodate many different forms of objects. Language was seen as important in the process of developing of concepts (Child 1993, Eysenck and Keane 1995, Miller 2003). Accordingly, theories of children's learning were seen as lying on a continuum of cognitive development as a result of both maturation and experience acting on innate concepts, in combination with social interaction and discussion with others. This process enabled individuals to construct an understanding of their environment allowing them to interact and react appropriately and therefore construct new knowledge from experiences.

It is in this way the child in the classroom is able to negotiate a learning pathway, supported by teachers and/or peers, through discussion, dialogue and activities, to encourage conceptual change and the construction of new knowledge. Learning experiences of this kind are personal and therefore individually significant allowing the learner to take possession of their learning, ensuring new knowledge constructed is meaningful and durable.

Ausubel (1973) proposed that in order to make learning meaningful, there has to be a plausible link between any new material introduced and current knowledge. If there appears to be no plausible link, new knowledge cannot be effectively assimilated into existing concepts. He also highlighted the context of the learning situation suggesting that the learner had to be disposed to learn meaningfully (Ausubel and Robinson 1973, McClelland 1983). So, if material presented in a lesson appears to be irrelevant, it will not be assimilated into the learner's conceptual structure. Only by making each encounter with new material relevant and related to the interests of the learner, he suggested, can effective and durable concept formation be facilitated. Ausubel considered his theory from the perspective of written and oral material, but it is possible to extrapolate these ideas to visual material, in that if the learner sees no relevance in what is being presented it is unlikely to contribute to learning.

That previous knowledge not only affects potential learning but could actually influence the way in which learning occurs was proposed by Osborne and Wittrock (1985) who suggested that existing ideas influence aspects of the sensory experience in that individuals select some aspects of the experience to be given attention. Selection of particular aspects influences the overall experience before links are formed from their memory. This results in meaning being generated which may or may not result in the replacing of the original idea. The use of a number of relevant and appropriate stimuli, in a multi-modal format, in conjunction with teacher input to generate memory links, in the form of recapping previous lessons, for example, was proposed as a pedagogical tool for teaching to ensure that meaning was generated from all aspects of lessons.

In a classroom situation children will have differing experiences of the world which potentially affect their learning in terms of their readiness and ability to engage with the content and materials of the lesson. Learning science is an intellectual engagement which transcends the mere rote learning bodies of facts, where thinking about the processes of science becomes important. Therefore teachers need to recognise that meaning can be problematic, as it is potentially differently generated amongst a class of children, whose thinking may differ considerably. Meaning, however, is often seen as the principle concern of pedagogy and as such determines the teaching techniques and strategies employed (Heywood 2001). Therefore pedagogy and teaching style are influential features of the construction of knowledge in the classroom.

Constructivist principles of teaching and learning originated and developed from many philosophical debates about the construction of knowledge. Presently it is considered that learners are best able to construct knowledge if:

- they are initially able to express their own ideas
- they are able to discuss these understandings with others and realise where their understanding differs from that of others
- their initial understanding is then developed through negotiated activities, dialogue and discussion with both the teacher and their peers, facilitating cognitive engagement with activities and media

- the context of knowledge construction, both socially and practically, is such that the construction of meaningful, durable and transferable understanding is achieved.

Wong *et al.* (2006) p 3

In the context of the science classroom this is typified by the need for children and their teachers to engage, explore, explain, elaborate and evaluate (Scott and Driver 1998). In terms of the requirements of the National Curriculum this can be seen as observe, hypothesise, predict, investigate, draw conclusions, and communicate to ensure the process skills of science are included in an individual's construction of knowledge (Harlen 1993).

All these aspects were described by Driver and Oldham (1986) in a teaching sequence which would allow for:

- orientation – engaging children with the phenomena
- elicitation – encouraging children to make their ideas explicit
- restructuring – through discussion leading to cognitive conflict
- application – of developed ideas to both familiar and novel situations
- review – reflection of changes in ideas to resolve cognitive conflict.

Driver and Oldham (1986) p118/9

These ideas form the basis of the constructivist pedagogy currently advocated for primary schools to ensure that learning is oriented towards the needs of individual children. Bell (2005) outlines the importance of children's ideas and their contribution to developing pedagogy from the findings of the Learning in Science Project (LISP) which promotes pedagogies to encourage classroom interaction involving dialogue and communication which contributes to conceptual development. Boulter and Gilbert (1995b) suggest forms of argumentation to promote discussion and dialogue in the classroom setting. The generative learning model proposed by Osborne and Wittrock (1985) initiated the notions that knowledge could be effectively constructed from children's ideas if the context was relevant and motivating, enabling a comparison through discussion of initial ideas and the accepted scientific consensus view, which could then be tested through problem-solving activities (Osborne and Wittrock 1985).

Knowledge created in this way is considered to be durable and meaningful (Ausubel and Robinson 1973) because it has been created by the learner, starting from the basis of their initial understandings and developed through a negotiated learning pathway, with the teacher as facilitator, resulting in the personal creation of knowledge for all individuals as suggested by Vygotsky's theory.

In order to facilitate the construction of knowledge and therefore learning, teachers must have an understanding of the learner's current level of knowledge and understanding. This can be achieved by posing open, challenging questions which require the children to think about their ideas in order to answer or construct an argument (Elstgeest 1985, Boulter and Gilbert 1995b, van Zee 2000). Expressing their ideas in this way means that an individual accesses their mental model to explain their thinking. This is necessary not only to ensure appropriate construction of, but also progression in, knowledge and understanding. Mental models, an individual's personal understanding, are critical to the engagement of, and with, constructivist practices in the classroom for both the teacher and learner. Children can then be encouraged to generate their own questions to be investigated further, leading to understanding generated from their own ideas (Bell 2005).

The reported importance of challenging a child's mental models to facilitate the construction of knowledge raises the question of the extent to which a teacher's knowledge and understanding of how learning occurs influence their pedagogical practices. Included in these practices is the way science content is viewed and presented (Chinn and Brewer 1998). Potentially, the teacher's own mental model of scientific phenomena might also contribute to determining how they will choose representational materials and use them to engage children in learning in lessons. A teacher's understanding of how learning occurs and their own knowledge of the topic being taught are two key factors which may relate to their choice of representational materials for use in their lessons.

2.4 Styles of teaching and their relationship to learning

A teacher's mental models of the content of the science they teach are likely to influence the style of teaching they adopt in the classroom. If they consider the content of science to be more important than the process of science then their lessons are more likely to be driven by presentation of facts and experimentation to prove these facts (Boulter and Gilbert 1995, Sizmur and Ashby 1997). Accordingly, a teacher's style is influenced by their views of learning which in turn will determine the activities they choose for the children and therefore also the materials they use in their lessons (Zimmermann 2000, Macleod and Golby 2003).

Differences in teaching styles and their consequences for children's learning were identified by a government commissioned study into school effectiveness (Galton and Simon 1980). Six teaching styles were identified by the ORACLE study, all of which had varying impacts on the learning occurring in the classroom. Two styles in particular had an impact on children's progress and these involved high levels of attention directed towards individual pupils, the most successful involved posing challenging questions and giving direct feedback, factors inherent in a constructivist paradigm. Other styles of teaching have been identified and described as models of approaches to teaching, informer, collaborator, personal models, behaviour modification models (Fisher 1991, Joyce *et al.* 2002).

Each model has its own distinctive characteristics with varying amounts of direct interaction with children and therefore structure to lessons, but none of them is mutually exclusive, in that aspects of some models are more appropriate to different forms of curricula (Joyce 1987) and groups of children (Wong *et al.* 2006). All approaches to teaching have their strengths and weaknesses which the teacher must adopt and adapt to ensure suitability for their particular educational purposes (Alexander *et al.* 1992).

Constructivist teaching practices involve active rather than passive learning, which may be excluded by some other styles of teaching. If active learning is viewed as children completing activities rather than being cognitively engaged in constructing knowledge through investigations to test ideas, there will be a tension between constructivist principles and the teaching style (Mayer 2002).

The initiatives arising from the publication of the Plowden Report (CACE 1967) placed emphasis on children being involved in practical activities in science lessons and were developed by the Nuffield Foundation. Currently active learning is not seen as just doing science experiments, the emphasis on practical work now involves children in designing their own investigations to test their ideas to answer questions they have posed rather than following 'recipe' type experiments found in more traditional classrooms (Millar and Driver1987, Leach and Paulson 1999, DfES 2005).

Traditional, didactic teaching methods are generally based on old learning theories. These suggest that simple tasks are engaged with before more complex tasks can be attempted, that only measurable learning is worthwhile and take no account of the contribution of prior knowledge in the learning process or the development of problem-solving skills (Taber 2000, Macleod and Golby 2003). However, traditional teaching methods may have a place in the classroom and may be particularly successful with small groups of children when knowledge of a particular investigative technique is required (Wragg 1991, Denicolo and Pope 2001, Joyce *et al.* 2002).

As a style of teaching, traditional methods rely on the assumption that science is a body of facts to be learned. This notion to an extent prevents science learning from being an active process, as indicated by the constructivist paradigm and reinforces it as a passive process. Whilst the curriculum is content-driven (Millar and Driver 1987) and dominated by summative testing, this is an inevitable consequence. The current curriculum therefore favours teacher-directed approaches, where the teacher remains in charge of the content of the lessons. It is also considered to be less arduous for teachers who, whilst in control of the content of their lessons, also have control over the children and the questions that might be asked (Hacker and Rowe 1997, Macleod and Golby 2003). Teaching for conceptual change (Posner *et al.* 1982), incorporating children's initial ideas, is however possible within the content-driven curriculum. As suggested by Hewson *et al.* (1998):

> A learning model does not prescribe a unique set of teaching sequences or strategies; and a particular teaching strategy does not determine the type of learning that will occur.
>
> p 199

The notions informing effective teaching and learning practices in primary science have deep historical antecedents (Osborne and Wittrock 1985). The importance of personal understandings affecting learning potential and therefore the personal construction of knowledge, initially posited in the Ancient world, again have relevance in contemporary science classrooms. The social nature of learning has moved science education from a body of facts to be assimilated to a voyage of discovery and interpretation relevant to individual learners and their previous experiences. Accounting for personal experiences in the learning process, in conjunction with the ideas of others, assists in the reformulation of personal mental models and therefore the construction of new knowledge.

The selection of representational materials teachers use in engaging children in activities to create opportunities for the construction of knowledge should therefore relate to an understanding of how learning takes place, the knowledge it is felt children need to understand and methods of involving children in these processes. Integral to the knowledge teachers feel children should have is their own personal understanding of the phenomena and their knowledge of the mental models potentially held by the children they teach.

Ascertaining the nature of the relationship between a teacher's style and classroom practises and the choice of and use to which they put teaching materials such as representations is fundamental to and informs the formulation of the research questions described in Section 2.12.

2.5 Model-based approaches to teaching and learning science

2.5.1 Personal mental models

Personal understandings of scientific phenomena derived from experience, which children and teachers take into the science classroom, have been termed mental models, each individual's plausible explanation of their experiences of scientific phenomena (Gentner and Stevens 1983, Norman 1983, Gilbert and Boulter 2000).

Norman (1983) termed these personal understandings, mental models:

> In interacting with the environment, with others and with the
> artefacts of technology, people form internal, mental models
> of themselves and of the things with which they are interacting.
>
> Norman (1983) p7

The term mental model has become a little confusing with various disciplines working with slightly differing interpretations. The interpretation for this thesis is that a mental model is a personal understanding of events, objects, processes and systems (Gilbert and Boulter 2000). These individual mental models are the existing, initial ideas that both learners and teachers take into classrooms where they are expressed, challenged and restructured by dialogue, discussion and interaction with activities. The act of expressing the internal models is an indication of personal understanding.

Mental models, therefore, are personal tools used for comprehension and thinking, as such they may be:

> ..small scale models of reality [which] need neither be wholly accurate nor correspond completely with what they model in order to be useful.
>
> Johnson-Laird (1983) p56

This view of mental models relates specifically to psychological explanations of thinking and reasoning. Understanding, the product of thinking and reasoning, could be said to be represented as knowledge. Thagard (1996) suggested that "knowledge in the mind consists of mental representations" (p 4).

Johnson-Laird (1999) argued that knowledge acquisition occurs when the mental representation currently held is manipulated in order to make sense of a novel situation. The context of novel situations has an impact on knowledge acquisition, and depending on the resolution of action taken a mental model may be unchanged or restructured.

Mental models are key factors in both the potential for building new knowledge and the interpretation of the context in which the new knowledge is encountered. But this individual view of mental models is no longer regarded as the complete explanation for the changes made in mental models on exposure to novel experiences and situations. Whilst there is no doubt that an individual can and will adapt their mental model in the light of novel circumstances, the effectiveness and durability of the changes are also dependent on the social context of the experience.

This idea has had important consequences for teaching science, where it was realised that these internal mental models not only differed from accepted scientific explanations of phenomena, but they appear to be resistant to change. On the other hand, mental models could also "provide predictive and explanatory power for understanding the interaction" (Norman 1983, p7).

Therefore mental models are internal and private until such time they are externalised as accounts or explanations. The act of expressing personal ideas can be extremely challenging as they are often held without verbal accompaniment (Norman 1983). Single ideas may be held in isolation from other ideas even though in reality they are related. If learning is to occur, these personal mental models need to be expressed so that teaching can facilitate linkage between them and new knowledge encountered, in an appropriate and meaningful manner.

Individuals are not normally called upon to formulate an explanation of their understanding of their experiences of scientific phenomena, but in science education they are. Mental models form the basis of individual understanding of the natural world and as such affect all aspects of learning in science.

On the basis that the concept of personal mental models provides the structure for understanding scientific phenomena, teachers' knowledge and understanding of potential mental models held by their pupils should impact on the activities and materials they provide in their lessons. The hypothesis suggests that teachers' knowledge and understanding of a topic does play a role in the selection of representational material. This leads to the question of specifically what criteria teachers actually use for the selection of materials for use in their lessons, which is fundamental to the research questions in this thesis.

2.5.2 Formulation of personal mental models

Science education aims to encourage the development of scientific knowledge and literacy so that future citizens are able to make informed decisions which not only affect themselves personally but are relevant to the world as a whole (Millar and Osborne 1998). That ideas about scientific phenomena held by children are not necessarily wrong but their own understandings of phenomena, potentially differing from the consensually agreed scientific explanation, has implications for the way science is taught (Gilbert and Watts 1983, Harlen 1985). Awareness of the likely mental models that children hold therefore provides the opportunity for comparison and discussion and a starting point for investigative activities and tasks, allowing the running of personal mental models and encouraging their expression, revision and reformulation.

Mental models which are discussed with others are expressed models. The use of expressed mental models for teaching and learning allows individual understandings to be accounted for in each and every lesson (Gobert and Buckley 2000). Working from the point at which the children's individual knowledge starts is achieved by encouraging the children to discuss their current knowledge, therefore forming an expressed model of their understanding of the phenomena under study. As activities are undertaken and materials accessed, the initial mental models have the potential to be adapted as new knowledge is encountered and incorporated into existing mental models and meaning is continually constructed. Mental models will only be changed if activities and experiences encountered in the science classroom are meaningful to that individual. With the teacher as a facilitator, the expression, evaluation and restructuring of personal mental models can be negotiated to engender conceptual challenges and subsequent conceptual change (Buckley 2000, Gobert and Buckley 2000).

Mental model re-formation is achieved by combining existing knowledge and new information with a task or activities, so if the existing model proves sufficient for the completion of the task or activity it is deemed to be successful and is reinforced and becomes more stable (Vosniadou and Brewer 1992, Buckley 2000). If, however, the mental model appears to have inconsistencies as the activity is undertaken, it may be rejected, revised or elaborated into a new mental model to support the activities undertaken (Clement *et al.* 1989, Chinn and Brewer 1993, Buckley 2000).

The process of rejection and revision of the whole or parts of a mental model continues until the model becomes increasingly complex and 'fit for purpose' (Clement *et al.* 1989, Clement 2000). The mental model may also be elaborated by the inclusion of parts of other existing mental models resulting from previous experiences. In this way increasing amounts of information are incorporated (Johnson-Laird 1983).

2.5.3 The role of representational material and explanations in reformulating mental models

If the value and importance of both teacher and pupil mental models in the learning process not only determines the content of lessons but also determines the effectiveness and durability of newly constructed knowledge, understanding the nature of mental models, their formation, tenacity and capacity for change, is a crucial aspect of the teaching process. Teachers' mental models will affect the material they choose to include in their lessons. This in turn will affect children's mental models as they interact with the material and activities provided by the teacher. If teachers have inaccurate mental models, it is possible that their explanations and interactions with children will affect mental model formation, revision and restructuring by the children. The ideas and explanations accompanying the materials included by teachers constitute their understanding of the science topic.

Representational materials are generally included in lessons to aid explanation. Explanations provided by a teacher imply they feel that the material will not stand on its own, that knowledge will not be appropriately constructed solely from the experience. Explanations may present alternative approaches to the material, therefore contextualising it for the group of children. The teacher's explanations arise from their mental model and the information they feel the children should have. How these explanations are undertaken is informed by the teacher's understanding of how learning occurs. If explanations are merely presentations of facts, they may not encourage conceptual engagement. Gilbert *et al.* (1998a) suggest that teacher explanations should "facilitate and suggest directions for, as opposed to inhibiting, subsequent questioning" (p 87). Teacher explanations which do not promote cognitive engagement and the generation of questions could be viewed as descriptions of facts.

Kenneth Craik proposed that explanations are possible because the human brain is able to process information. Observed external processes are translated into internal representations in the form of words, numbers and other symbols. These internal models are symbolic representations of the system experienced. Reasoning is the process of re-translating the thought model allowing the individual:

> to try out various alternatives, conclude which is the best of them, to react to future situations before they arise, utilize knowledge of past events in dealing with the present and future, and in every way react in a much fuller, safer and more competent manner to the emergencies which face it.
>
> Craik in Johnson-Laird (1983) p3

2.5.4 Expressed mental models in science

Mental models can be described as a way of interpreting the world around us (Johnson-Laird 1999). Reasoning and thinking require manipulation of mental models to deduce meaning and infer possibilities of the meaning of situations. In science, this interpretation can be envisaged in terms of associated words or symbols and can be expressed as numbers or symbols, in a formulaic manner or as syllogisms. Though mental models can be expressed in terms of syllogisms to indicate the deductive process, Johnson-Laird (1999) suggested that the mental models themselves were abstract and were not necessarily present in the form of an image. Thinking and reasoning occur when the mental model is used to deduce meaning from the various possibilities that become available from operating the model.

Deductions and inferences made by running mental models can be described in words. The words chosen by individuals to describe aspects of the mental model in the form of analogies and/or metaphors convey personal explanations in terms that others might understand. These explanations, expressions of mental models, require comprehension of the situation so that the mental model can be run effectively for understanding by others to occur (Johnson-Laird 1983).

Expression of mental models therefore allows discussion of ideas in a community, such as that of scientists or the classroom. Over time, expressed models may be adapted and restructured by the community until such point as they represent the consensually agreed structure, behaviour and/or mechanisms of any given phenomena or theory postulated. These consensually agreed expressed models contain elements which may no longer be explicit, having been modified during their restructuring. As the community agreeing the expressed model reaches a consensus, their understanding of the explicit and implicit aspects of a model need no further elaboration (Gilbert and Boulter 1995). Only when a consensually agreed expressed model moves into another community may the implicit aspects become important for the understanding of the observable explicit aspects, such as when scientific theories are introduced into the classroom. For complete understanding to occur in the new community the unobservable, implicit aspects of a model may therefore need to be made explicit.

So the position of mental models as aids to thinking, understanding and representing aspects of observed phenomena pre-supposes a number of different forms of mental model. Individuals will have different mental models of the same phenomena, formed by their individual previous experiences. Personal experiences, in different contexts, require differential operation of the mental processes on individual mental models, resulting in differential interpretations of similar situations. By expressing these individual mental models ideas can be compared with those of others using metaphors and analogies to support both communication and mutual understanding (Lakoff and Johnson 1980). Understanding expressed models in a community is therefore dependent to an extent on mutual understanding of the analogical and metaphorical devices employed during the exchange of ideas.

Ritchie (1994) defines metaphor as:

> a compressed simile, usually the substitution of one kind
> of object or idea for another, to suggest a likeness or
> analogy between them.
>
> p296

The use of metaphor and analogy thus enables ideas to be restructured in terms others may better understand, by for instance discussion and dialogue in the classroom.

2.5.5 Expressed models in the classroom

The teacher's role in the process of discussion and dialogue is likely to be dependent on their understanding of the phenomena, their view of how children learn and the way in which they use representational material in their classrooms. The children's understandings of the expressed model are dependent on their ability to understand the metaphors and analogies included. Therefore interpretation of an expressed model is dependent on the ability to interpret the devices used in its construction.

In science and science education, communicating ideas is very important. Scientists postulating and proving theories for acceptance by the scientific community need to ensure that their ideas and theories are accurately explained and understood. The same holds true in the science classroom. Teachers presenting scientific theories of phenomena may use expressed models developed by scientific communities, consensus scientific models, as representational aids. If both the implicit and explicit elements of these expressed models are not made clear, by allowing opportunities for comparison with the children's mental models, the potential for misunderstanding and misinterpretation is likely to be increased.

If expressed models are to act "as a bridge between scientific theory and the world as experienced" (Gilbert 2005 p11) they need to be carefully considered, chosen and used by teachers, to ensure appropriate bridging for children's own ideas.

In addition to using expressed verbal models in explanations, science uses physical models, such as those constructed by Ptolemy and Copernicus, to illustrate the operation of phenomena and to describe their mental models. These physical models contain indicators of the essential elements involved in the mechanisms operative in the phenomena, represented by physical objects thought most closely to express the modeller's ideas. Many expressed models imply other elements which are not present and some models lack elements of the system completely. If the expressed model is consensually agreed by the community constructing the model, the implied elements need no explanation. Only when the expressed model is used outside that community may the implied elements need to be expressed and explained. Thus the teacher's awareness of the devices, such as metaphor and analogy, used in the construction and depiction of an expressed model is likely to affect their interpretation of that particular expressed model and the way in which they use it in their lesson.

Expressed models used for teaching and learning may therefore need clarification. The different forms of expressed models and their relationship to an individual's mental model need to be clearly understood by teachers, and to some extent learners, if their use as tools for teaching and learning is not to cause confusion. Aspects of the models which are not visible may need to be made explicit to ensure that all the parts and their interactions are understood and potential areas of misunderstanding addressed. This will only be possible if the missing aspects, inferred elements, are known. The relationship between an individual's mental model and the expressed model and accompanying explanations, if present, will have a profound effect on the capacity for the construction of knowledge from that situation.

For these reasons, mental models are the starting point for all expressed models. The consensus across disciplines is broadly agreed that mental models of an individual's world are constructed to enable them to make inferences and predictions by interacting, thinking, reasoning and communicating these themes to others (Gentner and Stevens 1983, Johnson-Laird 1983).

Scientists working in the postulation and testing of new theories of observed phenomena use expressed models, in the form of mathematical equations and physical representations to communicate their own mental models, and have done so for centuries. Ptolemy (100-170) and later Copernicus (1473-1543) constructed planetaria, physical representations of their understanding of the Sun and planets in their orbits, to illustrate their thinking about the structure and behaviour of the Solar System. Their ideas had been formulated from observation and mathematical calculations. Without knowledge of the mathematical relationships, the relative movements and positions of the planets could not have been postulated, tested or proved. Some scientific phenomena are only or, at any rate, principally represented by mathematical formulae, Einstein's theory of relativity, for example.

Insight into an individual's mental model can be gained through their own explanation of a situation or phenomenon. Expression as explanation may take the form of symbols (diagrams, letters, numbers) or words. The words chosen for explanations may be analogies or metaphors, due to the difficulty of changing mental images into expressible verbal terms. Analogies and metaphors act as conduits for understanding as the explainer expresses their model in terms that generate understanding for others (Lakoff and Johnson 1980, Ortony 1998a). This highlights the importance of dialogue and discussion in the process of expressing mental models, with consequent implications for teaching and learning. The different types of expressed models, in the form of representations used in the classroom, also require explanation, dialogue and discussion if they are to contribute effectively to conceptual change in an individual's mental models. Individual's mental models and the various forms of expressed model play an integral part in teachers' understanding of how learning occurs in the classroom. Therefore the way representations are used and explained to the children will have an impact on the potential for knowledge construction from them. The hypothesis suggests that teachers' understanding of the way children learn is an important factor in their use of representational material in their classrooms, so this leads to the question of how they are actually used by teachers in the classroom.

Gilbert and Boulter defined mental models as "a representation of an object, an idea, an event, a process or a system" (Gilbert and Boulter 1998 p53). This definition of a mental model recognises the intensely personal nature of any learning experience, in or out of the classroom. The personal model can be expressed and extended on either a personal level or a group level. At a group level the model developed will be a consensus model. Both adults and children have mental models of phenomena, developed to differing levels of complexity and completion, depending on experience (Grosslight *et al.* 1991). Accessing personal models poses a number of problems of interpretation. The language, words and symbols used in explanations of mental models may not be immediately interpretable by others. The use of analogies and metaphors, referred to above, mediate meaning where it may not be immediately apparent.

Mental models may not be embedded in words, so expressing mental models may present difficulties in terms of articulation. It has been suggested (Norman 1983, Duit 1991a) that this difficulty of expression is because the mental model is incomplete and/or inaccurate. Expression challenges personal mental models to the extent that they need to be internally coherent in order for expression to be possible. A lack of coherence may not be the sole factor in the difficulty of expressing mental models as suggested above; verbalising ideas held internally without words is also a factor.

The formation of mental models appears to be widely held as a way of interpreting information and experiences (Gentner and Stevens, 1983, Norman 1983, Johnson-Laird 1999, Buckley 2000, Gilbert and Boulter 1998 & 2000). In science, models are used to express individual and group ideas. If these models are then used as tools for teaching, as a means of guiding understanding, we have another aspect in which the formation of personal mental models plays a key role: the interpretation of expressed models used.

Representational materials selected by teachers are in fact expressed models devised by other people. As such they will have been constructed in terms of the creator's mental model leading to the expressed model, the representation. The creator may be aware of the scientific community's consensually agreed expressed model and follow the same outline. But the teacher still consciously or subconsciously interprets the expressed model in terms of their own knowledge and understanding of the phenomena and their interpretation of the way children learn, in order to select what they consider to be appropriate material. This implies that the teacher understands and is able to interpret both the implicit and explicit aspects of the expressed model and the version the creator has created. In this respect, the form an expressed model takes may also influence the choice of representational material and the way it is used in the classroom, which is a core element to the first two of the three general research questions.

2.5.6 Models in the public domain and their representation

Mental models are highly personal and private, but there are other types of model identified as being in the public domain. Gilbert and Boulter (2000) suggest the following types of model:

Expressed models: the placing of a mental model in the public domain

Consensus models: expressed models agreed by the community using them

Scientific models: consensus models that have been tested, reviewed and gained acceptance and used in the development of thinking

Historical models: superseded scientific models

Curriculum models: historical and consensus models adopted by school curricula

Teaching models: simplified combinations of scientific, consensus and historical models developed by teachers and/or learners to assist understanding of particular phenomena

Hybrid models: aspects of several scientific, historical or curricular models merged for teaching purposes and used as a coherent whole.

Gilbert and Boulter (2000) p 12

A combination of any of these models is likely to be found in science classrooms depending on the teacher's interpretation of the content of the lesson and their view of how children learn. All of the above types of model could be encountered in a number of formats. These formats, called modes of representation (Buckley and Boulter 2000), can be one or a combination of:

> *Concrete:* – 3D material models: e.g. an orrery
> *Verbal:* – descriptions and explanations that are heard or read
> *Visual:* – diagrams, animations and video sequences
> *Gestural:* – movements of the body.
>
> p 47

Thus, the potential for the use of models as tools for teaching and learning is comprehensive and extensive. The different types of expressed model allow the representation of different entities, either a depiction of reality or a depiction of the imagined reality. In either case they allow the possibility of testing mental models and making predictions about operant behaviours and mechanisms (Buckley and Boulter 2000, Gilbert 2005).

If we consider the use of expressed models in the classroom, though the implied meaning might be clear to the teacher, their use as tools for the construction of knowledge, and therefore facilitating understanding, is limited to the level of interpretation by children. The level of interpretation may result from the manner in which the expressed model is constructed.

Mayer (1989) suggested that good models for teaching should have seven criteria. They should be complete, concise, coherent, concrete, conceptual, correct and considerate. He suggests that models should be used for explanations and presented prior to or during a lesson, in order to make effective tools for concept formation and therefore knowledge construction.

The ability to interpret, understand and construct knowledge from an expressed model therefore must relate in some way to the way to the criteria and content of its construction. If models are "small scale representations of reality" (Johnson-Laird 1983) representing a target system (Gilbert 1983, Norman 1983), and assuming that they contain the criteria and are used in the manner suggested by Mayer (1989), they should be able to supply learners with all the information they need to understand any particular phenomenon.

In fact this does not always happen, as the ability to read a model is dependent on an individual's mental model, their current understanding of the phenomena being represented and their interpretation of the model being presented. This can lead to discrepancies between scientifically accurate knowledge, as potentially represented by the model, and personal knowledge, resulting in incomplete understanding of the phenomena being presented. Given that personal explanations may initially be inaccurate, opportunities for constructing and restructuring knowledge from models should be carefully presented to minimise any likely insufficiencies in the model which may reinforce initial misconceptions. The importance of discussion and dialogue as interrogatives in this process allows for the community of the classroom to agree on their interpretation of the model being presented and therefore its intended meaning. This in turn may be dependent on the way teachers use models in their lessons.

Different types of model may be needed to illustrate different aspects of an object or a system if a single example proves insufficient for generating understanding and knowledge construction. George Kelly in his personal construct theory used three objects to force comparisons rather than direct choices between two items. If three examples of representations could be presented at any one time then comparisons of their attributes would highlight their similarities and differences (Denicolo and Pope 2001). This would enable the implicit and explicit aspects to be compared and differences to be discussed and resolved.

Working with representations could be viewed in the same way as scientists working with their models, to promote thinking and expression of ideas, as suggested by Harrison and Treagust (2000), making teachers aware of any misunderstanding the child already holds and of further misunderstandings which may arise from incorrectly interpreting the models they are using.

Teacher explanations accompanying the use of representations in science classrooms have the potential to enhance the meaning constructed, by facilitating and suggesting directions for questioning (Gilbert *et al.* 1998a). By adding verbal and gestural explanations, aspects of representations which are implicit can be made explicit, if the accompanying explanations are coherent and relevant.

The mode of representation used may influence the level of explanation made by the teacher (Kress *et al.* 1996, Ogborn *et al.* 1996). Concrete models, such as an orrery, lend themselves to verbal and gestural accompaniments as they are 3-dimensional and can be viewed from various angles (Buckley and Boulter 2000). This potentially allows the opportunity for individual parts of the model to be highlighted, by gesture, directing attention to a particular area for explanation or description. Parts of the model may be moveable, potentially allowing relative directional movements to be indicated. Visual models in the form of 2-dimensional representations, illustrations and photographs, are limited in this respect and the use of gestures can only imply direction of movement to be indicated (Buckley and Boulter 2000). Gesturing is not limited to indicate aspects of representations; it can and often does accompany verbal explanations and expressions of ideas (Alibali *et al.* 1997).

Hence, the extent to which a teacher's knowledge of the phenomena being taught determines how much additional information, in terms of description and gestural movement, they add to the representational material is likely to be an important aspect to researching how representations are used in lessons.

The construction of meaning within the classroom community results therefore from a combination of the teacher's understanding of the phenomena, their understanding of the way children learn, the representational materials they have chosen to illustrate this phenomena and the way they use the representational material in their lesson. If the representational material is not 'fit for purpose' then the potential for the construction of meaning is likely to be limited, which is fundamental to the third of the three general research questions.

2.5.7 Role of gesture in communicating with models

A gesture, movement of the hands, head or whole body, can be used to express ideas or add a further dimension to the expressed ideas (Crowder and Newman 1993). Children and adults have been found to gesture frequently when explaining scientific or mathematical principles (Church and Goldin-Meadow 1986, Crowder and Newman 1993). Gesturing is thought to add a non-verbal layer of communication to explanatory speech (McNeill 1992, Crowder 1996). It also aids explanation when specialised vocabulary, such as that associated with scientific and mathematical principles, is either not known or poorly understood (Crowder and Newman 1993). Gesture is a constant feature in the expression of ideas which is rarely afforded significance (McNeill 1992, Crowder and Newman 1993).

In addition gesture may serve as the model itself, as suggested by Boulter and Buckley (2000), where the movements of the whole or parts of the body are used in the absence of, or in addition to, a concrete or visual model. Direction and magnitude, entities difficult to convey in concrete and visual models, can be implied by degrees of movement of the whole or parts of the body.

Children are adept at seeing and using gestures (Alibali *et al.* 1997, Goldin-Meadow 2004) indicating the importance of gesture as a means of communication in the classroom. Crowder (1996) found four types of functional gestures used by children to express their ideas:

> As redundant to speech.
> As enhancing speech.
> As an alternative carrier of scientific meaning.
> As interwoven gesture-talk. p17

Gestures redundant to speech add nothing extra to the argument being explained. The other types of gesture add varying amounts of information where expression of the ideas verbally is difficult. Difficulties in verbal expression arise because of lack of scientific or appropriate vocabulary (Crowder and Newman 1993). Gestures used instead of words can influence the complexity of verbal utterances. There could be an additional explanation; that the mental model is held without words, and gestures serve to provide a bridge for expression.

In addition to physical movements of the body, facial expressions are another means of non-verbal communication. Movements of the face and the direction of gaze can carry meaning (Kress and van Leeuwen 1996 and 2001, Unsworth 2001). That the gaze of an explainer is often fixated in a space beyond the person being spoken to, Crowder (1996) suggested, is an indication that the explanation was not solely for that person but was serving as a personal problem-solving device, in effect accessing their mental model and running it whilst formulating the explanation.

McNiell (1992) proposed that the use of gesture in conjunction with speech helped to mediate thought "There is a synthesis, and at the moment of synthesis language and gesture are combined into one unified presentation of meaning" (p246) supporting the notion of accessing mental models during explanations.

The context and space in which gestures are made can also convey meaning (Neill 1991, McNeill 1992). Expansive arm movements away from the body can imply enormous size or personal or social confidence. Conversely, small movements close to the body might imply lack of confidence in subject knowledge or feelings of personal or social inferiority (McNeill 1992). Accurately interpreting the size of the gesture and the space used to gesture could give significant insight into the mental model being expressed and the expresser's confidence in its validity, adding an extra dimension to understanding of the scientific phenomena under discussion. The tenacity of alternative ideas held may also be discernable from the size and space used for gesturing, giving the teacher further opportunities to understand and therefore accommodate children's expressed alternative ideas into their planning for activities. When the teacher gestures, it may be an indication of their confidence in their personal knowledge of the phenomena they are illustrating and explaining.

Goldin-Meadow (2004) proposes that gesture is an integral part of communication and that they are "hand movements that accompany and are directly tied to speech" (p315) and as such they "point out referents of speech or exploit imagery to elaborate the contents of speech" (p315).

Gesture can therefore form a significant component of a teacher's repertoire and when used in conjunction with representations may have an important effect on the potential construction of meaning (Kress *et al.* 1996, Ogborn *et al.* 1996, Unsworth 2001). The teacher's choice of representations and knowledge about the way viewers decode and interact with them to construct meaning, therefore, become crucial. It may be particularly critical if the teacher uses the same representational material to represent more than one entity, where the use of gesture may not convey the differences in intended meaning of the altered representational target.

The gestures employed by teachers are therefore likely to be both conscious and unconscious. As gestures are an integral part of human communication this is to be expected. Maths teachers have been found to gesture at the rate of three gestures per minute (Goldin-Meadow *et al.* 1999). Maths contains many complex concepts, which Goldin-Meadow found that teachers gestured to explain. So, it might be not be unreasonable to assume that science teachers would gesture at a similar rate, as they explain scientific concepts to a class. Crowder (1993) found that both children and adults gesture when they are explaining maths and science problems and phenomena.

Children are adept at reading gestures, developing the skills for decoding them before the equivalent verbal skills (Crowder and Newman 1993). In fact, a teacher who did not gesture would probably be seen as difficult to understand and perhaps boring. Certainly it is difficult to attend completely during communications that are absolutely devoid of gestures. Speech of this type, devoid of gesture, has been found to decrease the level of meaning communicated (McNiell 1992).

Many of the gestures used by teachers though made unconsciously will therefore convey meaning to children. For example, a teacher's initial stance at the commencement of a lesson with arms crossed in front of the body is classified as a closed stance. This stance suggests that the speaker is not open to interruption or interested in engaging in communication, so is interpreted by the children as 'I am ready now and waiting for you', and not solely communication closure (Neill 1991).

Other unconscious gestures, such as hair arranging and face touching, are seen as indicating discomfort in some sense (McNeill 1992, Sturken and Cartwright 2003, Norris 2004). For some teachers this could be interpreted as being nervous about the class they are teaching in terms of their ability to engage with or control them, or awareness that their subject knowledge may not be sufficient to sustain questions from the children. Such gestures from a child may give teachers insight into the levels of confidence of the child's contribution.

Confidence in verbal explanations can be displayed by emphasis gestures. Emphasis gestures can be repeatedly used during explanations. These gestures, sometimes called beats, serve as gestural punctuation and enable the viewer to discern which aspects of the communication are of importance to the speaker (McNeill 1992). Children would be well aware of the significance of the beat gesture in conversation, and are likely to use them themselves when talking to each other and their teacher (Alibali *et al.* 1997).

It might also serve to alert the children to words and phrases important to the explanation, i.e. key words. As children are already able to decode beats as points of emphasis, they would be likely to be able to decode the teacher's emphasis via beats of the important parts of explanations and may even use the beats as cues to interpret which aspects of the explanation they need to retain (Goldin-Meadow *et al.* 1999).

As children are assumed to be adept at decoding gestural movements (Crowder 1996, Goldin-Meadow 2004) it is therefore reasonable to assume that they will be able to separate those gestures which are part of general communication and those which relate directly to any representational material.

Gestures, such as pointing with either a finger or part of the hand, will direct the children's attention to a particular aspect of a representation. Attention can also be directed by the head or the eyes, though this could be counterproductive in a classroom for the majority of the children, who may not be able to see relatively small gestures from their position in the classroom. Explaining or demonstrating complex interactions, such as relative orbital movements of the planets is likely to require expansive, clearly observable gestural movements (Crowder and Newman 1993).

When explaining the relative movements of the Earth and Sun it is almost impossible to achieve any level of sense unless the orbits are illustrated. In book illustration this is achieved by using devises such as arrows, to indicate direction of movements, conventions that have developed as historical consensus (Tufte 1997). Conventionally, straight arrows are used to indicate linear movement and curved arrows are used to indicate circular movement. Different thicknesses of arrows are generally used to indicate differences in magnitude (Tversky *et al.* 2000). These ideas can be reinforced by gestures, where the gesture repeats the movement indicated by the arrow. In addition to the repetition, a gesture can also indicate relative velocity and planes of movement, adding useful information to a model or illustration, which is difficult to express in 2-dimensional illustrations and static models (Buckley and Boulter 2000). These gestures can also serve to clarify any confusion arising from the children's misinterpretation of the movement indicated by arrows.

Demonstrating the rotation of the Earth using a concrete model, such as a globe or ball, raises other questions about the way gesture is performed and read. There is no research which has investigated the way the children read the teacher's gestures performed in these circumstances. The direction of rotation performed may be the opposite of reality, with expectation that children will translate the gesture appropriately. 'Mirroring' is common in social situations during verbal communications, and small children will mirror parental movements, but how children interpret teachers' movements does not seem to have been investigated (Alibali and Goldin-Meadow 1993, Crowder 1996). Therefore teachers' gestures may be misinterpreted, by mirroring, thus leading to misunderstandings of the explanation.

Gestures therefore supply part of the additional information required to fully interpret representations used to illustrate complex mechanisms and can encourage the development of new ideas, but only if the representations and gestures used are conceptually coherent. However accurate explanations with accompanying gestures are, it maybe possible that they hinder rather than enhance conceptual progression and therefore understanding. If gestures and speech are considered as ephemeral as suggested by Goldin-Meadow (2004) they become "transitory modes of communication disappearing as soon as they are performed" (p319).

If children are to understand the additions made by speech and gesture they have to understand them sufficiently to be able to incorporate them into their knowledge construction at the time they are performed.

Gesture therefore potentially serves to enable the teacher to gain an insight into children's understanding of phenomena, to add material to a representation, to highlight aspects of a representation and, to some extent, serve to indicate their own understanding of the phenomena (Crowder and Newman 1993).

The hypothesis suggests that one of the key factors in the selection and use of representational material is the teacher's knowledge of how children learn. The use teachers make of gesture in their explanations may therefore be important in indicating how they understand children will interact with the material they are using and the aspects of the material they feel the children need to be aware of to construct their own understanding from it, which is reflected in the second of the three general research questions.

The effective use of gesture to enhance the communication of representational materials is likely to be partly determined by the teacher's understanding of the way visual materials are viewed and interpreted and in particular the way children 'read' visual materials. Therefore this may inform the criteria teachers use to select representational material to use in their lessons.

2.6 How learners view representations

2.6.1 Theories of visual perception

Representational material used in the classroom has to be viewed and interpreted by both the teacher and the children. The teacher selects the material, so therefore has looked at and interpreted the material and presumably decided that it is fit for their purposes of illustrating some aspect of their lesson. The children will view the material in the context of their current and previous science lessons and their current knowledge. Therefore, their mental models of the phenomena being studied contribute to construction of meaning from what they see. So theories of visual perception are important for understanding how learners are likely to interpret the representational material they are presented with.

Visual perception is the acquisition of information from the environment via the visual organs, the eyes. This at its simplest level could be looking – using our eyes. In fact, there are several complex mechanisms involved in processing light patterns into accurate and detailed interpretation of what is seen (Zeki 1995).

Perception has been defined as:

> ...the means by which information acquired
> from the environment via the sense organs is
> transformed into experience of objects, sounds, tastes etc
>
> Roth (1986) p81

Light patterns land on the retina at the back of the eye causing light sensitive cells, rods and cones, in the retinal layer to 'fire', releasing chemicals which stimulate nerve cells, transmitting a message along nerve pathways to the optic nerve and into the visual cortex, situated at the rear and base of the brain. There are several layers of receptors within the visual cortex which receive and interpret the differing signals as they arrive.

The interpretation of these signals is currently thought to be the point of perception. The manner in which the visual cortex interprets these cues received through the visual pathway has given rise to a number of theories of perception (Zeki 1995).

Theories of visual perception encompass a variety of approaches which can be summarised in terms of the emphasis they place on particular aspects of the process:

- a constructivist, cognitive interpretation emphasises the importance of previous knowledge in interpreting the signals
- a computational approach which seeks to simulate the mechanisms of perception with computer programs, thereby modelling the mechanisms thought to be involved
- a neurological approach that explains perception purely in terms of chemical activity in the nerves and brain.

based on Rookes and Willson (2000)

The theoretical approach considered most relevant to this study is the constructivist, cognitive interpretation of visual signals. The visual signals are devices used to create an image. Therefore the images contain information in terms of the conformation and configuration of these devices. If the configuration of devices used to create the image cannot be interpreted, the potential for the construction of meaning from that image is limited. Knowledge is constructed from the interpretation of the visual signals and the context of its viewing. So it is important that visual material used in the classroom is not only engaging, in that children will want to look at it, but that it also is appropriately interpretable by them. The cognitive, constructivist approach to perception proposes an explanation for the way the conformation and configuration of devices are interpreted.

The Gestalt movement proposed a principle of perceptual organisation suggesting that viewers construct understanding from the individual aspects of visual images they encounter. Gestalt translates literally as the shape or pattern of a whole, implying the sum of constituent parts is greater than the sum of each individual part. The Gestalt movement proposed that perception was the result of construing an object as a whole rather than the constituent parts and that fundamental to this was a principle they called Pragnanz, literally, simplicity.

> Of several geometrically possible organisations
> that one will actually occur which possess the
> best, simplest and most stable shape.
>
> Koffka (1935) in Eysenck and Keane (1995) p33

This key principle was further defined by four laws defining levels and type of organisation of parts within a whole. These Gestalt principles have not been undermined or superseded over the years and the general principles have been used as starting points for further theories of perception.

Whilst Gestaltian theory proposes that visual perception results from seeing an image or object as a whole rather than as its individual, constituent parts, the process by which this is achieved can be said to be constructivist, in that if partial objects or images are observed, the perceptual mechanism strives subconsciously to complete them to make the best sense of what is being viewed, to construct meaning from the parts that are seen.

Gregory (1966) proposed that there was a facility within the structure of the brain that enabled inferences to be made from parts of objects viewed. For example, objects viewed from angles where their true shape and size is not immediately obvious, such as a half open door in the distance, are still interpreted by the viewer as a door. This led Gregory to propose a theory of perceptual hypothesis, where incomplete or obscure objects in the visual field were supplemented by unconscious inferences derived in part from past experiences (Gross 1996, Rookes and Willson 2000). His work with illusions illustrates this idea. Figure 2.1, commonly know as the Müller-Lyer illusion, shows two lines of equal length with inward or outward pointing 'fins'. The angle of the fins determines how we interpret the length of the line, inwards shorter, outwards longer. Gregory suggests that these illusions result from operating a visual hypothesis, where the best inference is constructed from the visual information available and combined with previous visual experiences to construct meaning (Gregory 1966).

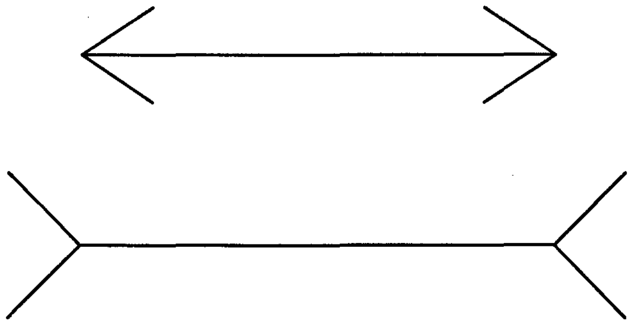

Figure 2.1 The Müller-Lyer Illusion.

The fact that we know we are looking at an illusion, we can measure the two lines and find that they are equal, yet are unable to escape from its illusory effect, Gregory suggested was evidence that visual perception is immediate and not cognitively controlled. The visual hypothesis serves to equip humans with the skill rapidly to assess their surroundings, a survival strategy. Combining the immediacy of perception with the long term conceptual understanding of many perceptual events allows individuals to plan and describe their actions (Gregory 1990):

> Our perceptions must always strike a balance between
> rapidity and ease on the one hand and accuracy on the other.
> If we are too quick, we may overlook important events;
> if we are too accurate, perception is retarded
> to such an extent as to be ineffective."
>
> p238

Conversely, Gibson (1904-1979) felt that there was no higher order of cognition involved in visual perception, suggesting that patterns of light entering the eye were sufficient for recognition to occur. The patterns of light, which he termed the optic ray, enabled the viewer to distinguish depth and texture within the visual field, which were sufficient to provide information for the viewer, so perception was direct (Gross 1996, Rookes and Willson 2000). Gibson believed that visual perception was not solely that which happened through the eyes and brain but was dependent on factors in the environment in which perception occurs as well, leading to his theory being known as an ecological theory. Gibson's theory of direct perception used affordances as part of the means of interpretation of the optic array, where affordances give meaning to the objects perceived. Affordances, the ability to recognise both the object and its use, enable recognition but are in part dependent on the physical, psychological and physiological situation of the viewer, the viewing environment. So a thirsty person being handed a glass would perceive it as a drinking vessel, whereas a non-thirsty person may see it as a container for flowers, pencils or bread sticks depending on what else was present in their surroundings (or their mind) at that time (Gregory 1990, Rookes and Willson 2000).

Marr (1982) took this notion further, devising computer programs which could recognise pre-programmed shapes and translate the parts into a whole. In order to do this he suggested that images, or viewing instances, could be characterised by their basal components, lines, edges and blobs, which the viewer combined to make sense of the view.

This visual process therefore produced a series of representations, which provided increasingly detailed descriptions of the visual environment, giving information about light intensity and thus the number and outline of objects; information about shading, motion, texture and shape resulting in the formation of the primal sketch by detection of varying light intensities produced from the visual information consisting of edges, lines and blobs (Marr and Hildreth 1980). Interpretation of the dimensions of the representation used levels of shading and texture to provide information about an object's relative position and depth.

The visual world does not consciously consist of edges, lines and blobs so there must be a further mechanism which enables related elements to be grouped together to form separate objects. Marr suggested principles that could resolve the ambiguity present in the primal sketch of lines, blobs and edges, which, along the lines of the Gestalt principles, grouped similar elements together and categorised them (Gordon 1990, Eysenck and Keane 1995, Gross 1996, Rookes and Willson 2000).

Theories of visual perception, therefore, draw together, from different starting points and using different principles, a number of ideas about the importance of whole objects and their parts, and the context within which images are encountered which has implications when considering viewing images. This relates to the third general research question regarding cognitive coherence, as interpreting images may have implications for the sense made of images and therefore the potential meaning that can be derived from them.

2.6.2 The perception of images

Any image contains a number of elements which give visual clues to its overall content. In works of art, these drawing conventions can be categorised and so give a common structure with which to view any number of images. Willats (1997) suggests that "pictures are made up of lines of ink or patches of paint." (p7).

These basic elements of lines and patches of paint form the 'primitives' of the whole image. Primitives are the most elementary units of shape available in an image. Here there are similarities to the Gestaltian and Marr theories discussed above.

Willats (1997) developed systems which categorised images by basic structures included in their construction. Projection systems map spatial relations within the image into correspondence within the whole picture. Denotation systems map features from the image onto the corresponding picture primitives, the most basic elements. Thus every detail contained within a picture can be isolated and related to the other parts within the picture, from the picture primitives to the whole scene and the inter-relationship of those parts. This system can be seen in part as having Gestaltian features, the whole being a sum of its parts, but with each part having integrity of its own.

Willats (1997) considered that art, in the contemporary sense, hardly existed in previous times and cultures and that art in antiquity performed a different function, depicting religious texts or conveying technical information. Decorations on ancient Egyptian, Greek and Roman artefacts were either silhouettes or line drawings, which are, using Willat's system, picture primitives, and the most basic form of representation, with few interpretative elements in each scene (Hölscher 1987). So called higher forms of art began to appear in the form of perspective drawings. Here the use of orthogonal lines to convey perspective and use of scale allowed greater meaning to be imposed on depicted scenes.

As cultural and social expectations led to the assumption that works of art conveyed meaning other than and in addition to that depicted, information became a feature and a function of representational material (Tufte 1983). Paintings depicted not just the person sitting for the portrait, but also conveyed their social status by the inclusion of particular artefacts and detail in items of clothing. The inclusion of metaphorical references, in older paintings, usually biblical references, resulted in paintings conveying more information than immediately obvious on initial viewing.

Therefore quantities of information can be carried in visual representations. Representations that intend to communicate large quantities of information are graphs and maps, first originating as early as 1750 Tufte (1983). Tufte (1983) suggests that maps are very powerful instruments, as "the eye tends to pick out linear patterns even in random noise." (p26). The random noise he refers to is the background. Here again is the notion that sense of the whole is made from the parts, consisting of lines and patches of colour or shading.

In addition to the lines, blobs and edges contained in images and the tendency to group together similar elements within the image, there is a 'meaning' attached to images. Thagard (1996) suggested that "Pictorial representations capture visual and spatial information in a much more useable form than lengthy verbal descriptions." (p105).

The construction of an image, and the elements contained within an image, imply that an image contains more than just the visual elements and that something is to be communicated. Viewing an image, therefore, can be performed on several levels. At the most basic level visual interaction with an image will occur subconsciously, as the component parts of the image are perceived and processed by the eyes and brain. Interpretation of what is perceived based on previous viewing experiences and current knowledge can then take place.

If images, such as those in school textbooks, are intended to convey particular information, is it reasonable to assume that this information is clearly and unambiguously presented so that there is little room for misinterpretation. The way information is presented in an image results from its construction in terms of the lines, blocks of shading and colour which contribute to the meaning that can be constructed from images and representations.

As images and other forms of representation are created by individuals, the devices used in their construction can be identified and categorised and their contribution to the construction of meaning assessed, as discussed in the following section.

2.6.3 The construction of images used in science teaching

Images in teaching materials, therefore, are visual devices from which meaning can be made. Images in the classroom may be presented in isolation or appear in combination with text or verbal explanation. Whether this meaning complements or replaces accompanying text depends on the context of its appearance. An image in an advertisement may be meaningful without any textual additions. Our daily lives are dominated by a variety of images, with and without text, which govern behaviour, convey instructions and communicate information (Martins 2002). Images may be static or moving depending on the medium they are expressed in. Static images such as those to be found on signs and in books are constructed to convey meaning to (almost) anybody encountering them. Often such signs are used where language may cause difficulties of comprehension and have developed from the ISOTYPE system devised by Otto Neurath (1935) to present information in a concise and unambiguous way by reducing the amount of what Tufte (1990) called 'noise'. Neurath's work resulted in the huge variety of pictorial signs currently encountered in our environment, depicting places, actions and information, the telephone handset to indicate the presence of a telephone booth for example.

Images often accompany narratives in children's books, where the aim is to engage the child with the text by portraying important or interesting episodes from the narrative in a visual form (Robson 2002, Arizpe and Styles 2003). In school textbooks images may be used to illustrate aspects of the text for demonstration or clarification (Mayer and Gallini 1990). The interpretation of the validity, relevance or appropriateness of accompanying images depends on their proximity to the text and their physical appearance, their visual appeal (Hartley 1994, Mayer 2002).

Construction of images, therefore, is also context dependent. Images which intend to convey meaning as information such as graphs, maps and diagrams usually contain minimal amounts of extraneous lines or colours which would detract from their content (Tufte 1997). Images which convey instructions also need to be clear and unambiguous (Hartley 1994). Images which are intended to communicate ideas do not need to be unambiguous; indeed many artists intentionally build ambiguity into their pictures as part of the effect (Gombrich 1960). It is not intended to analyse artistic representations in works of art in this thesis, though some note needs to be taken of the fact that the images children and their teachers encounter in their daily lives will to varying extents be influenced by the artistic cultures surrounding them and therefore be part of their experiences.

Art forms, whether paintings in the National Gallery or sculptures in town centres, have the capacity to evoke an emotional response (Gombrich 1960, Berger 1972). Diagrams and illustrations in science textbooks on the other hand are more likely to be regarded as emotionally neutral, as they are intended to convey factual information. Whether this is the case in reality is not clear, though given that images can provoke emotive responses, it might be that images encountered in textbooks are assumed by viewers to require an unemotional response.

Images constructed to accompany expository text, as found in science textbooks, require not only knowledge of the subject being illustrated but also knowledge of the techniques required to best communicate that knowledge. They can then either be a graphic depiction, involving perspective, colour and shade, or a diagrammatic depiction using lines to delineate edges, inclusive features and extremities (Willats 1990, Hartley 1994). Willats (1997) suggests that it is the positioning of lines within drawings which leads the eye to particular points in the whole, therefore denoting important aspects. In this way an impression of the intended meaning is gained and this is clarified by the presence of additional lines, spaces and blocks of colour and shading to create a complete picture. He suggests that the ability to interpret images is because humans are "very good at extracting features such as edges from the varying light intensity of light as it falls on the retina" (Willats 1990 p244).

In this sense Willat's ideas support Gestaltian and Gregory's theories of perception, where the noticing of lines and edges enables interpretation of the images portrayed. This has consequences for viewing two dimensional portrayals of three dimensional objects.

Architectural drawings intended to represent one aspect of a house in its truest form are drawn without any shading or lines of perspective, as these aspects are deemed an unnecessary distraction from the depiction (Willats 1990). This leads to the consideration of the different intentions of drawings and illustrations. Combining Willat's ideas with those of Marr described above, the different types and systems of depiction could be said to be orientated to different viewpoints, a perspective depiction shows an object from the viewer's point of view, whilst perspective-less depictions show an object-centred view point (Willats 1990).

The appearance and formation of representations therefore determines the way they are perceived. Theories of visual perception explain how the physical attributes are interpreted by the eyes and perceptual mechanisms of the brain. Theories of visual analysis such as that proposed by Kress and van Leeuwen (1996) add a further layer of interpretation to looking at visual images and objects, by including the effects of social and cultural influences on the perceptual process.

Kress and van Leeuwen (1996) suggest that the construction or design of images follow these social and cultural influences, making them culturally interpretable. Images from other cultures will therefore require some form of explanation before they are fully understood. The importance of personal and cultural influences on the meaning that can be derived from any single viewing instance are therefore context dependent relying on an individual's interpretation of the cultural rules.

In summary, there are a considerable number of influences surrounding the construction of images used in science teaching that may in turn have a profound effect on the suitability of the materials for a particular class of children, which is another of the key factors underlying the research questions. For the teacher, awareness of the likely way children will interpret what they are being shown and the likely meaning that will be constructed from it is necessary to discover the strengths and weaknesses of visual materials and the context within which they are viewed.

2.7 Selecting and interpreting representations

2.7.1 Representations as expressions of mental models

Gilbert and Boulter (2000) described a model as an instance of an object or event or a combination of events and objects in a system. A representation could therefore be said to be an expression of a mental model. The construction of a representation necessitates that the constructor has a mental model of what they are representing in order to be able to create it. Kress *et al.* (2001) suggest that representations are usually created to fulfil a purpose describing them as *"a matter of active, deliberate design"* (p2).

Sturken and Cartwright (2003) compare the representation to reality:

> Representation is distinct from simulation,
> in that representation declares itself to re-presenting
> some aspect of the real. p365

These are the key features for the use of representations in classrooms. Representations are created visual texts which stand for an aspect or aspects of a real event or object (Kress and van Leeuwen 1996, Unsworth 2001, Gilbert 2005). They are intended to be used as aids to learning, for the presentation (or transmission) of facts. Representational material presented in any mode, for example, 3-dimensional physical models or 2-dimensional illustrations, photographs, diagrams or formulae, all serve the same purpose – presenting a verbal or textual situation in another, visual, format.

Representations designed for use in classrooms are therefore likely to have been designed to convey specific meaning (Sturken and Cartwright 2003). This may give authority to representations which might not be valid. If a representation is presented as an interpretation of a real phenomenon, it is likely, especially in a science classroom context, to be viewed as authoritative and accurate, because of the cultural assumptions made about science and scientific texts. This notion derives from the manner in which scientific theories are written and talked about (Lemke 1990). Science writing has developed into a particular genre of formalised, 'dehumanised and dogmatic' writing using specialised vocabulary (Lemke 1990 p33), to ensure minimal ambiguity. This belies the real nature of scientific discovery which utilises mental models, expressed models and discussion in the discovery, development and testing of new theories (Gentner and Stevens 1983, Mylan 2002, Gilbert 2005). Rather than presenting dogmatic instances of reality as facts, representations could be used in a similar manner in the classroom, to challenge individual mental models and develop conceptual understanding.

An example of this is a concept cartoon. These cartoons were devised by Keogh and Naylor (1999) to provide opportunities for knowledge construction by promoting discussion and debate about the statements made by the cartoon characters. This highlights the notion of the classroom as a community where knowledge is negotiated by members expressing ideas and alternative suggestions until a mediated meaning is agreed.

Whilst not actually representing a scientific phenomenon, these cartoons encourage thinking and discussion about scientific phenomena. The statements made by the cartoon characters are common misconceptions previously identified by research (summarized by Pfundt and Duit 1991) and in any group of children it is likely that they will represent one or more of the misconceptions held by them. Constructing a consensual agreement about the cartoon will require the children to access and express their mental models and revise, restructure or reject their initial ideas. Individuals in the group should then be able to explain the phenomena to another or engage in activities to test their decision. Currently, concept cartoons do not appear in textbooks generally used in science classrooms, but as individual representations to introduce topics and stimulated discussion.

The types of representation a teacher selects may reflect their understanding of the way children view visual materials. Conversely, the reasons for selection may be as prosaic as availability at the time of the lesson with little or no attention being given to the way the children are likely to interpret what they are seeing. The fitness for purpose of any or all representations used may therefore be determined by factors other than their potential contribution to knowledge construction.

2.7.2 Selection of representations to address possible misconceptions

In science lessons the influence of children's ideas about the phenomena they are studying will also impact on their interpretations of visual material. Children's personal mental models have been shown to affect their willingness to engage with the material of lessons and to accept, at a cognitive level, the differing interpretations put forward. If representational materials are to be used effectively to encourage children to construct accurate and durable meaning about scientific phenomena, the physical and cognitive attributes of looking at that material should be balanced and integrated with the known misconceptions children will use as their viewing lens (Sturken and Cartwright 2003).

Addressing misconceptions and providing plausible and coherent cognitive pathways for understanding requires that any representation used is clearly defined. The use of the same materials in differing contexts, to represent different phenomena or aspects of phenomena, could potentially confuse or undermine any cognitive links formed from earlier instances of viewing the artefacts. Therefore the way in which a teacher uses the representational material and their views of the way children view and interact with such materials has important consequences for addressing, restructuring or forming misunderstandings.

This is particularly critical in topics where direct observation and interaction with the phenomena are not possible as in parts of the topic of the Earth in Space. Ensuring that materials used for representation of objects, systems and behaviours of scientific phenomena are consistently, cognitively coherent in terms of their visual construction will contribute to accurate, durable and meaningful knowledge construction, which is another of the key factors leading to the derivation of the general research questions.

2.7.3 Representations in the science classroom

Teachers use representations in a variety of ways for a variety of reasons (Kress *et al.* 2001, Peacock and Cleghorn 2004). Any instance of the use of a representation in a classroom setting implies that meaning is thought, by the teacher selecting it, to be present. By selecting and using a particular representation the teacher must consider that, at some level, meaning is sufficient for the students to understand what is being shown. This does not necessarily mean that children viewing the representation will construct the same meaning the teacher selecting the image or model constructs or intends for them to construct. Science text is an expression of science which is separate from the real world and therefore the teacher becomes the chief interpreter when they choose material for their lessons (Peacock and Miller 2004).

If representational materials are assumed by that teacher to convey meaning, these meanings can be assumed to have already been identified, in the process of selection. This process does not necessarily identify the meaning the children will construct from them, nor does it imply that the teacher consciously examines representations for the meaning that may be constructed from them. Often in primary science classrooms, the teacher is not a science specialist and may be uncertain about their own science knowledge, leading to the use of materials selected and supplied by an appointed subject co-ordinator (Peacock and Gates 2000, Heywood 2001). Whilst the subject co-ordinator's knowledge of the phenomenon being illustrated may be scientifically accurate and the representation chosen an appropriate expression of that phenomenon, it does not necessarily follow that other teachers will view it in the same way. Phenomena may be represented in a variety of formats which can all be considered as 'objects' to be viewed.

The ability to 'read' images and therefore representational objects is dependent on an understanding of the grammatical rules of visual imagery (Kress and van Leeuwen 1996, Prosser 2001, Unsworth 2001). But an understanding of visual grammar is only part of the process of looking at and interpreting what is seen.

For children to access the information made available in objects and derive meaning from them, these objects or representations of them, have to be viewed and interpreted. Initially this viewing is at the level of visual perception. Once the components of a representation have been interpreted via visual perception, meaning can be made from their combination, relative positions and overall context.

A part of the context in the use of representational material is the classroom setting and the way such material is introduced and used with children. Representations used during teaching sessions with younger children, especially, are rarely used in isolation and are often accompanied by explanations in the form of speech and gesture (Kress *et al.* 2001, Unsworth 2001, Peacock and Cleghorn 2004). The use of speech and gesture implies the provision of additional information to highlight and/or explain particular features of the represented objects and mechanisms of inter-relationship and inter-dependence. Gesture and explanation may form part of the representation itself as suggested by Boulter and Buckley (2000). Additional information, not explicit in representational material, may be added in cases where the material is considered to need further explanation before it can be understood.

The selection of the type of representation will to some extent depend on the purpose it is expected to fulfil. A photographic image may be regarded as a depiction of reality whereas a physical model may be regarded as an analogous depiction of a whole or partial object or system (Kress *et al.* 2001, Prosser 2001, Unsworth 2001, Sturken and Cartwright 2003). Increasingly science textbooks contain photographs in addition to diagrams and text as the cost of printing colour photographs decreases relatively (Martins 2002, Hardy 2004). Animated sequences and physical models may be seen to represent the operation of an object or objects within a system, relating their spatial orientation to the mechanism of their interdependence and the consequent behaviours of the system as a whole over a period of time (Mayer 2002).

Hence, the way representational material is viewed is likely to be affected by the mode in which it is presented. Understanding how children look at and interpret different modes of representations is therefore likely to be an important aspect of researching their use in science classrooms.

2.8 Types of representation used in teaching science

2.8.1 Introduction

There is a wide range of types of representations commonly used by science teachers, reviewed below, which are fundamentally different in their construction. Each mode of representation presents information in distinctly different formats, although by their very nature none is without its limitations in presenting science phenomena. These differences are likely to have a significant effect not only on the way that the teacher uses the materials but also on how both teachers and children view them and interpret the scientific content presented in them. These are key factors included in the formulation of the research questions in Section 2.12.

Concrete, i.e. physical, models of objects and systems have the property that they are 3-dimensional and can be viewed on all sides. This differentiates them from most other forms of representations including 2-dimensional representations, illustrations, diagrams, photographs or animations that need to be constructed in such a way that dimensionality is implied as necessary.

2.8.2 Concrete models

Concrete models are physical representations of an object, system or event. They are 3-dimensional, giving depth, dimension and perspective to representations of phenomena (Buckley and Boulter 2000). If there is any movement possible in the model, they can be used to show behaviour of the system. The advantage of concrete models is that they can be constructed on a different scale from reality allowing, for example, large models of the inside of plant or animal cells, or small models of the Solar System (Norman 1983, Gilbert 2005). The potential for altering the scale of depiction allows for almost any entity to be examined. This is an advantage for scientists working on the resolution of their theories, and it also has relevance in the classroom, where concrete models of objects or systems can be introduced to children for them to test their mental models against (Buckley and Boulter 2000).

Commercially produced concrete models are only one form of this type of model used in the classroom. Teachers often construct their own concrete models from materials they have to hand. An example of this is the Qualifications and Curriculum Authority (QCA) recommended model for the objects in the Solar System (QCA 1998). A number of differing sized spheres, ranging from a peppercorn to a large beach ball, are suggested in an activity for exploring the relative sizes of the Sun and planets. These teacher-constructed models, teaching models (Gilbert and Boulter 2000), have the advantage for schools in that they are relatively inexpensive and readily available. On the other hand, if objects used to show one aspect of the Solar System are then used in a different context, the change of meaning of the object in the new situation may not necessarily be clear to a viewer, as the conceptual entities introduced on one model may be carried through to another context.

Scientists use models to mediate meaning and they can be used for the same purpose in the classroom (Buckley 2000, Gilbert 2005). Interchanging objects in concrete models implies changes of conceptual entity for that object which needs to be understood and agreed by those accessing the changed model so that attributes of former models are not carried over to the new model.

Using everyday, familiar objects as components of concrete models requires that those viewing the model understand the analogical implications of the objects and their position in the model. Again, if the analogical references are changed from model to model, there is potential for misinterpretation and misunderstanding of what is being represented (Gilbert 2005).

Since concrete models have the potential for depicting systems and behaviours in the system, in addition to objects within the system, the scaling of both relative distances and movements is important. Whilst a peppercorn being carried around a large beach ball may depict the orbital pattern of the Earth around the Sun, the velocity, direction and distance of these movements cannot be replicated on this model. Verbal explanation and gestural movements can add these dimensions.

Whilst concrete, 3-dimensional models need no additional cues to indicate depth, 2-dimensional, visual models do require cues to indicate depth. In photographs, this occurs as a result of the shadows formed by light on the subject and reflections from other objects. In other types of 2-dimensional visual models, indication of depth and dimension relies on artistic drawing conventions to produce the appearance of perspective and thus on the viewer being able to interpret the marks made and drawing conventions included in the image (Gombrich 1990, Willats 1997).

Textbooks contain visual models as images in the form of diagrams, photographs and coloured illustrations. These images are viewed in conjunction with text on the pages in the context of science lessons or activities. The context of their viewing is likely to contribute to the meaning constructed from them, but the manner in which individual images are created will also contribute to the meaning that can be made from viewing them.

2.8.3 Books

The different types of books used in schools, though not normally considered as representations themselves, contain representational material. The type of book that this material appears in may influence the way it is perceived. Textbooks are commonly found in secondary schools, but are also used in primary science lessons. Reference books, for general information or specifically for science information, are likely to be found in primary school libraries and are therefore generally intended for use outside the classroom context. Whether books are used in conjunction with the teacher in a lesson or for personal study, they have to be accessed and the pages of information interpreted by readers.

2.8.3.1 Science textbooks

In schools the use of textbooks is common, both at primary and secondary level, though the use of textbooks is more usually associated with personal study in secondary schools. In primary schools textbooks are usually used as reference texts for teachers and children rather than for personal study (Woodward 1987, Stern and Roseman 2004, Walpole and Smolkin 2004). Topic-specific reference books are generally made available for use in primary school science lessons, as children are set tasks to research information for themselves in the form of projects. It is known that primary school teachers use information from textbooks to create materials, such as worksheets for children. They also use them as reference texts for themselves for lesson preparation and as aide memoirs during lessons (Peacock and Cleghorn 2004). Using textbooks to re-present information implies that the teacher aims to make it more accessible for the children they are teaching. Peacock (1997) found that teachers alter information as they transfer it from book to worksheet. Redesigning printed material necessarily requires the teacher to have secure subject knowledge, in order that essential aspects are not omitted or changed. If essential aspects are omitted or changed, the potential for creating cognitively incoherent material is greater. If the materials produced by the teacher contain cognitive inconsistencies, then they are unlikely to provide the children with appropriate opportunities for learning from them (Peacock and Cleghorn 2004).

Textbooks for primary school science are available usually as part of a comprehensive published scheme and can be found in many schools. The amount of use made of these books is uncertain; it is not a topic that appears in research journals, though one would have thought that publishers would be interested in the use made of books they have invested time, money and expertise in developing. Several studies have looked at science textbooks and evaluated their effectiveness (Larkin and Simon 1987, Reid and Beveridge 1990, Stylianidou *et al.* 2002,) as tools for teaching in secondary school classrooms, but none appears to have considered information teachers might add to the content of the books by means of explanations, as is generally the case when such books are used in primary schools.

Studies have shown that children experience numerous difficulties in interpreting information in science textbooks (Reid and Beveridge 1990, Peacock 2001, Peña and Quílez 2001). A study made in conjunction with this study showed that primary school children have difficulty in extracting information from reference books (Marsh and Litson 2002). Meyer *et al.* (1990) found that interpretation of material in text books was affected by the relative positioning of text and image.

The text in reference and science books tends to be expository, providing explanations using technical language. Children are expected to read and understand this genre of literature when it is presented in science lessons (Peacock 2001, Peacock and Cleghorn 2004, Reid and Beveridge 1990). Children appear to have preconceived ideas about the type of books they consider appropriate for their use and are actively discouraged from accessing some texts purely by their appearance (Marsh and Litson 2002).

Textbooks used in science lessons, therefore, seem to be regarded by children as different from the books encountered in other subjects and certainly different from the fiction and non-fiction books they read for pleasure (Peacock 2001, Marsh and Litson 2002). The content and format of science text and reference books may therefore determine the children's response to them in their science lessons. One reason for the predominance of published schemes in primary schools may be to overcome the perceived difficulty of accessing scientific texts.

Published schemes of work solve many of the problems teachers face selecting materials as they generally contain background information, texts for children and appropriate, often differentiated, worksheets to complement work in lessons. Such schemes of work are also useful for teachers who are not confident in their subject knowledge, as background scientific principles to topics are usually explained and the topics themselves tend to build on each other in a logical progression, making preparation for lessons less time consuming and giving some security in content knowledge (Woodward 1987, Martins 2004, Peacock and Cleghorn 2004).

Publishing houses have their own criteria when producing science textbooks (Woodward 1987, Hardy 2004). Considerations of presentation, often driven by costs, affect the amount and quality of information presented per topic or page (Walpole and Smolkin 2004). Scientific accuracy may be sacrificed to in-house styles such as the amount of pictorial material per page of text, the types of images used and the printing techniques employed, resulting in drawings and diagrams, rather then photographic images. The resulting differences in style and layout are features which will appeal to different individuals depending on their priorities and the use they intend to make of the materials (Robson 2002).

Traditionally, textbooks for older children contained extensive textual explanations of scientific phenomena accompanied by black and white line diagrams (Pintó and Ametller 2002). This layout is probably derived from the notion of 'science as truth', a notion stemming from the debate between Thomas Kuhn and Karl Popper, interalia, about the reality of scientific facts. Kress and van Leeuwen (1996) cite Galileo's scientific work as devoid of emotive attributes, such as colour, as he represented the physical aspects of his observations.

The idea of science as truth results in a series of irrefutable laws which are presented in such a way that they are not embellished with unnecessary artwork (Pintó and Ametller 2002). Older science textbooks therefore tend to appear visually sparse and lexographically dense. A move to improve the visual appeal has resulted in the brightly coloured, textually sparse, modern science books, particularly for younger children. Improved printing techniques and the demand for increased visual interest, spurred by the plethora of the visual imagery experienced daily through a variety of media, has also contributed to the change of format for science textbooks (Martins 2004).

It is now common to find books for older children, studying for GCSE and A level science examinations, containing a large amount of colourful illustrations on pages with a limited amount of relatively large font, often coloured, text. This layout, though arguably more appealing for readers, restricts the amount of information on a page. Combine this with the large amount of illustrative material per page and the result may less comprehensible than publishers and authors might wish. Figures 2.2, 2.3 and 2.4 show a comparison between three science textbooks dealing with the dispersion of light passing through a prism. The older textbook (Figure 2.2), used as part of an 'O' level physics course (Abbot 1963), has a line diagram taking approximately one third of the page. The text is dark and closely printed and the language used is scientifically technical, making the page today appear intense. The second example, (Figure 2.3), is from a book used as part of a GCSE double science course (Lewis and Foxcroft 1996) and shows the same physics principle but the text is paler, more widely spaced and covering only two-thirds of the page. The diagrams are paler, larger and continue into the blank space left by the adjusted text. The language used is less scientifically technical, reading like a chatty explanation rather than an exposition of facts. The third example, Figure 2.4, is taken from a book intended for use with Years 7 - 9 science groups (age 11 – 14 years old) and uses a photograph instead of a diagram (Chapman *et* *al.* 2001). There is very little scientifically technical information included in the text. The text itself is produced in a modern, relatively large, well spaced font, making it relatively easy to read. Unfortunately the inclusion, on the same page of the information about colour filters could potentially be confusing.

Contemporary textbooks, therefore, appear to be printed with larger text, colourful illustrations and photographs in order to appeal to their audience. The 'Twenty First Century Science Project' found that they had to reduce the number of words per page in materials designed for 15 -16 year olds, in order to appeal to their readers (Millar 2006).

In reality the above examples, despite their different appearances, are all of the same type. They are instructional texts, laying out information about a particular topic, in a particular way using mainly scientific language and as such are likely to present children with difficulties of interpretation (Pintó and Ametller 2002, Stylianidou *et al.* 2002).

A completely different form of textbook for children has emerged from the constructivist philosophy for teaching science described earlier. Keogh and Naylor (1999) produced a series of cartoon images of children stating ideas about a range of scientific phenomena. The cartoons are intended to promote discussion as each idea is potentially plausible in the light of the misconceptions commonly held, identified by research (Driver 1981, Driver *et al.* 1993). An example of a concept cartoon for the physics principles illustrated above is shown in Figure 2.5.

Images in texts are often thought of as adding information. It is expected that the illustration is to be viewed in combination with the text and elements of the illustration related to the appropriate aspects of textual explanations, therefore adding clarity to the text. Reid and Beveridge (1990) found that children find it almost impossible to ignore illustrations accompanying texts, which suggests that they are an important aspect to take into consideration for children decoding pages in books. If this is the case then illustrations should be as accurate and relevant as possible to complement textual explanations and clarify areas of possible misunderstanding or ambiguity (Stylianidou *et al.* 2002). In order to understand both textual explanations and their accompanying images a certain level of conceptual knowledge is required. Decoding material without prior knowledge can lead to misinterpretation, as the viewer 'reads' the material through what Stylianidou *et al.* (2002) calls their theoretical lens, their understanding at that time. Images are often thought to present meaning directly and simply, but even simplistic illustrations contain elements and conventions which may need explanation before their meaning is actually clear. Images are often thought to present meaning directly and simply, but even simplistic illustrations contain elements and conventions which may need explanation before their meaning is actually clear (Mayer *et al.* 1996, Stylianidou *et al.* 2002).

2.8.3.2 Illustrations in science textbooks

Reid and Beveridge (1990) suggest that the relationship between text and pictures affects the way children learn. They found that less able children spend more time looking at pictures and appear less competent at relating the content of the text to illustrations, whereas more able children use the pictures to clarify points they read in the text. They suggest that all children, irrespective of ability, find it 'difficult to ignore pictures' (p86), as almost two-thirds of the children in their study looked at pictures before accessing the text. If this is the case then it is critical that pictures accompanying text are accurate and unambiguous for the text to be interpreted with complete comprehension. Mayer *et al.* (1996) also found that the text accompanying illustrations also affected the attention paid to both text and the image and therefore the meaning that could be made from viewing them together.

The readability of a text presents another issue for comprehensibility. There are several readability tests which can be applied to text extracts to establish their suitability for particular age groups (Hartley 1994). Publishers consider the readability of texts as an important feature, consequently influencing the type of vocabulary, length of sentences and size of font for any given piece of text (Eschborn 1989, Hartley 1994, Robson 2002). Science books for younger children are often introduced at a point in their learning where the children are, in effect, emerging readers, which can cause difficulties with decoding as science books tend to be expository texts, whereas all the reading material they have encountered to this point may have been narrative in nature (Peacock 1997). Once reading fluency has been achieved, little time is allocated to the decoding of expository texts and the relevant skills required for their successful comprehension. The Literacy Scheme aims to address reading and writing of every genre of textual material, including 'scientific' writing, but this may not be sufficient to carry over into science lessons (Sutton 1992, Peacock 1997). This potentially poses considerable problems for less confident or less able children who do not progress to the required level of experience or learning for decoding expository texts and may then rely on illustrations for clarification. Illustrations accompanying expository texts therefore need to be clear to avoid misunderstandings (Peacock 1997). The reality is that illustrations are not necessarily as helpful for understanding texts as authors, teachers and children assume them to be (Mayer and Gallini 1990). This situation applies across the curriculum subjects and is not specific to science, although it is particularly relevant in science education where many scientific phenomena are represented visually.

27 : Dispersion and colour

It had been known for centuries that small fragments of colourless glass and precious stones glittered in bright colours when white light passed through them, but it was not until the middle of the seventeenth century that Sir Isaac Newton investigated the problem systematically.

Newton's work on this subject arose out of the need for finding a way of removing coloration from the images seen through a telescope. At that time this instrument had recently been invented by a Dutch spectacle-maker named Lippershey.

Image redacted due to third party rights or other legal issues

[redacted]

FIG. 271. Newton's first dispersion experiment

Newton's experiment with a prism

Newton began his experiments by making a small circular hole in one of the window shutters of his room at Cambridge. Light from the sun streamed through this hole and made a circular white patch on the opposite wall. On placing a triangular glass prism before the hole, an elongated coloured patch of light was formed on the wall. Newton called this a *spectrum*, and noted that the colours formed were in the order Red, Orange, Yellow, Green, Blue, Indigo and Violet (Fig. 271).

The theory which he put forward to explain the spectrum was that white light consists of a mixture of seven different colours. The refractive index of glass is different for each colour, so that when white light falls on the prism each colour in it is refracted at a different angle, with the result that the colours are spread out to form a spectrum. It should be noted that when the light is incident on the prism as shown in Fig. 271, it is refracted towards the base of the prism, the violet being deviated most and the red least. The separation of white light into its component colours by a prism is called *dispersion*. Strictly speaking,

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Newton's experiments with prisms and coloured light

Does the prism put the colours into the light? Or is white light just a mixture of all the colours of the spectrum which the prism has separated? Isaac Newton did some experiments to try to find the answer. He used a beam of sunlight passing into a darkened room through a small hole in the blind.

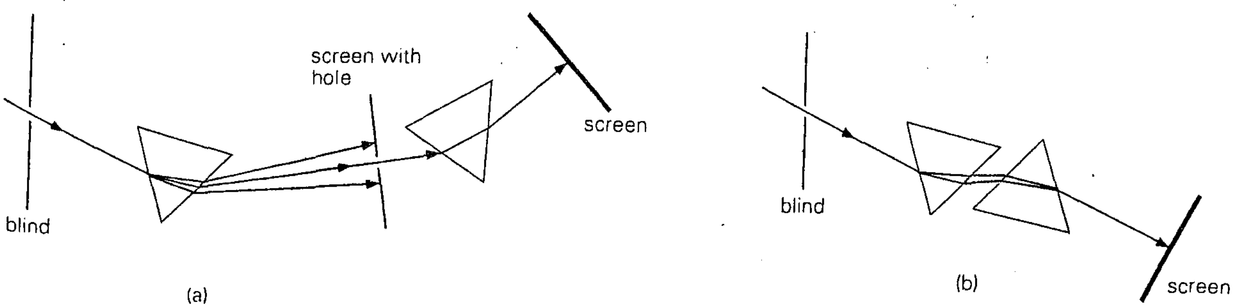

Fig 19.29

Fig 19.29 shows two of his experiments. In the first (a), he had a screen with a hole in it to allow through only one of the colours produced by the first prism. He then used a second prism to see if any more colours appeared. No new colours were produced. Green light, for example, could not be split up by the second prism into any other colours of the spectrum.

In the second experiment (b), he recombined all the colours produced by the first prism by using the second prism the other way round. He found that white light appeared on the screen.

As a result of these experiments he decided that the colours are there in the original light all the time and that the mixture of all the colours appears to us as white.

The prism sorts the various colours by bending each colour by a slightly different amount, the bluest colour being bent the most. We now know this happens because each colour has a slightly different speed in the glass.

The colour of objects

Why do objects have colours? If there is no light in a room, we cannot see any of the objects in it. We see an object because some of the light which falls on it is scattered into our eyes. Yet different objects can have different colours even though the light falling on them is the same.

The reason for this is that a red object has a surface which scatters the red parts of the spectrum but absorbs most of the green and blue parts. So we see it as red. With a blue object, the red and yellow parts of the spectrum are mostly absorbed, whilst the surface scatters the blue parts strongly.

Figure 2.3 Physics Years 7-9 (Lewis and Foxcroft 1996)

Image redacted due to third party rights or other legal issues

[redacted]

Figure 2.4 Eureka 2R Years 7-9 (Chapman *et al.* 2001)

Image redacted due to third party rights or other legal issues

[redacted]

12.11 Prism

What do YOU think?

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Light

Figure 2.5 Light (Keogh and Naylor 1999)

Looking at images appears initially to be straightforward, but in reality interpretation requires a high degree of skill to decode information and therefore its meaning. Illustrative drawings contain information which has been 'filtered' through the eyes of the artist who created them. Many conventions of drawing, unconsciously applied by artists, need to be understood by the viewer (Tufte 1990, Willats 1997). For example shading to indicate dimensionality and angled lines indicating perspective may, if incorrectly interpreted, indicate a completely different meaning to a viewer. The *trompe-l'œil*, illusionary drawings such as the Müller-Leyer lines are an example of the misinterpretation possible from incorrect or inaccurate viewing of images. The Gestalt laws of perception suggest ways in which images are interpreted, with parts of images being perceptually interpreted to make the most sense of the lines and shapes contained in the image. If the viewer is inexperienced, as in the case of children, the conventions may not be recognised or understood. In this case inherent perceptual criteria will predominate and the viewer will look for recognisable shapes within the illustration, to make some sense of what they are seeing and attempt to relate this to their existing conceptual knowledge and any new concepts presented in the text. Misinterpretation of visual material is therefore a very real possibility and is likely to lead to misunderstandings of the scientific phenomena being illustrated.

It is now accepted that a number of misconceptions about scientific phenomena are held by the majority of children (Pfundt and Duit 1991). These misconceptions can survive to adulthood unless viable alternative concepts are presented in such a way that changes to the underlying conceptual frameworks are engendered and mental models are restructured. Illustrations in books therefore need to be created in such a way that these common misconceptions are addressed or at least not reinforced. Ambiguities in illustrative and textual explanations of scientific phenomena could lead to rejection of new ideas and retention of existing concepts for want of a convincing alternative.

Peacock (1997) found that teachers often reproduced material from books for their classes, feeling that the material presented in books was too difficult for the children to comprehend. Whilst this ensures that children access information considered appropriate by the teacher, it is a form of translation and is dependent on the teacher's understanding of the topic to include all relevant and pertinent aspects of the page. Peacock (1997) found that pages reproduced as worksheets were often incomplete, as important areas relevant for understanding phenomena were omitted, though the expository text was generally reproduced. This has important consequences for teaching science (and teaching in general) with respect to representative material. It is quite acceptable for teachers to rewrite material they feel is too difficult for the children in their class to interpret, but in doing so it is vital that they understand the way children interpret illustrative material and respond to different genres of text (Peacock and Cleghorn 2004). An assumption may be being made by the teacher, in the light of the fact that science texts are held to be knowledgeable and accurate, though difficult to read and understand (Lemke 1990), that to present an easier option by reproducing these texts either as worksheets or drawings on the board they are providing scientifically accurate material (Peacock and Cleghorn 2004).

Translation, which is in effect what teachers are doing when rewriting published texts, requires a large degree of content knowledge about the particular topic being addressed if important areas of conceptual content are not to be missed or misrepresented, leading in turn to possible misinterpretation by viewers/users and therefore misunderstanding (Peacock and Miller 2004). If illustrations and diagrams are reproduced from books onto the board for children to copy into their exercise books, there is an opportunity for children to change the material again as they copy it. If the concepts illustrated by the teacher-produced materials are incompletely understood by the children copying them, the likelihood of inappropriate changes occurring will be increased. There is no published research which details the way children copy teacher notes and diagrams from the board into their books, so this has been included in the formulation of the research questions and relates to the cognitive coherence of representational material.

2.8.3.3 Colour and illustration

Another form of representation is illustration, for this thesis defined as coloured drawings. Illustrations differ from diagrams in that they may not be intended to depict a reality, but are included to break up text, highlight an aspect of accompanying text or take the place of a photograph (Arizpe and Styles 2003). Illustrations are common in primary school classrooms. They appear in most reading material and as posters on classroom walls. They form part of a child's visual world at school. The type of illustration varies from coloured drawings that appear to mimic photographs to cartoon depictions of objects and events. As they are constructed, drawn by someone, they may not hold the same authority as perceived in photographs. Increasingly illustrations include colour, as technology enables its inclusion in a greater range of situations and the relative costs of its inclusion decreases (Gates 2004).

Colour is an important aspect of illustration and is a useful tool for delineating separate areas, for directing attention to particular parts and implying importance. Gombrich (1990) and Kress and van Leeuwen (1996) both suggest that one of the primary effects of the inclusion of colour is to produce an emotive response. Colours which evoke emotions (Gombrich 1990) are one level of communication, and have socially and culturally constructed associated meanings, for instance, red warns of danger, to English viewers. Children will have their own understanding of the meanings of colours, shaped by their experiences, which may influence the way they perceive colours presented in representations. The use of colour in illustrations could therefore be a distraction from the intent if its use is arbitrary rather than intentional (Tufte 1997, Kress and van Leeuwen 2002).

Intentional colours used in scientific diagrams are conventions developed by the scientific community and agreed as conveying appropriate meaning. Colour conventions used for depicting planets in the Solar System often show Mars as red and Saturn as yellow as demonstrated by concrete models manufactured for use in schools (Educational Insights 2001, Cochranes 2004, Kidz Lab 2005). If these conventions are not are not fully understood by viewers the potential for creating misunderstandings increases. Tufte (1997) suggests that the use of colour in presenting information should be carefully considered. He quotes Paul Klee who said that good painting was "simply putting the right colour in the right place" (p83).

But it is not that simple. The way the eye perceives colour, via rods and cone cells embedded in the retina, 'firing' as light of different wavelengths strike them, enables interpretation of the colours in an image. Some colours complement each other, enhancing the visual appeal. Proximity of different colours can change their hue potentially resulting in the diminution of importance of particular areas (Tufte 1997, Kress and van Leeuwen 2002). The inclusion of colour and hue in illustrations can therefore affect the way they are interpreted.

Marie Neurath adopted the ISOTYPE technique of seemingly simplistic form of depiction in her science books (Neurath 1960 and 1974). She introduced the idea that every time a ray of light was depicted it would be a straight yellow line, whereas heat would be indicated by a straight red line. The result was precise and clear drawings to represent mainly the structure, but occasionally the behaviour, of scientific and geographical phenomena. The colour convention of yellow to represent light and red to represent heat appears to have started here. Understanding colour conventions, such as yellow lines for light, aids the interpretation of coloured drawings.

Using colours in illustrations which do not conform to the conventional context is therefore likely to cause misinterpretation. So, whilst colour is regarded as a useful addition to illustrations, its use needs to be carefully considered: "The scant benefits derived from colouring data indicate that even putting a good colour in a good place is a complex matter." (Tufte (1990) p83).

2.8.3.4 Reference books

There are a large number of science reference books widely available and commonly found in primary school classrooms and libraries. These books can be topic specific, dealing with one aspect such as electricity, or in the form of encyclopaedias, dealing with a range of science topics, usually in subject order, as opposed to general encyclopaedias which are arranged in alphabetical order. These books are often written by scientifically knowledgeable authors, lending credibility to the content but the structure and presentation of information is subject to publishing houses' particular criteria. Publishers' priorities affecting textbooks produced for school use also have an impact on the large number of information and reference texts commonly available. Page layout, font size and the types and quantity of illustrations included per page are subject to cost considerations (Apple 1989, Hartley 1994, Robson 2002). Inclusion of colours, whether in the form of photographs, drawings, illustrations or artistic representations of phenomena, is subject to conventions and criteria not necessarily consonant with accurate factual representation of scientific facts.

The children in the various pilot projects undertaken prior to this study when presented with pages from reference books invariably stated that they were difficult to read and that they would not attempt to access the information. This was clearly demonstrated in a Best Practice Research Study (BPRS) (Marsh *et al.* 2002) undertaken during the initial stages of this study, which found that children were reluctant to access information from pages in reference books. They found isolating individual pieces of information from the page extremely difficult. This confirms the earlier contention that children, even fluent readers, are not necessarily able to transfer their reading skills from narrative reading books to expository reference texts and their accompanying illustrations (Larkin and Simon 1987, Lemke1990, Mayer *et al.* 1996). Different decoding skills are required to sift through large amounts of textual information and illustrations and children may need support if they are to access these books for comprehension to develop their learning and conceptual knowledge base. Support in decoding information from books can be achieved with teacher explanation and gestures to indicate areas of particular importance on the pages.

2.8.3.5 Photographs

Photographs increasingly form part of the illustrative material produced for children (Walpole and Smolkin 2004). Photographs are generally regarded as depictions of reality (Gombrich 1990, Sturken and Cartwright 2003). This belief has cultural origins dating from the beginning of photography, where the instance of a photograph was seen as capturing a moment in time, as opposed to a painting which was not necessarily an accurate portrayal nor, because of the time involved in its completion, a moment in time (Emmison and Smith 2000, Rose 2001, Sturken and Cartwright 2003). Rose (2001) refers to the "apparent truthfulness" (p19) of photographs resulting from the way in which photographs are understood. If they are thought of as snapshots of an instance in time which records the way things actually appear this does not account for the possibility of posing and distortion. The notion of the photograph as a depiction of reality will probably decline in validity as digital manipulation of photographic images becomes common.

Viewing a photograph requires interpretation of the composition. The relative position of objects and subjects within the frame and the contextual aspects of background may have been arranged by the photographer to convey a particular meaning. If the viewer is unable to interpret the intended meaning the image will lose its intent (Lister and Wells 2004). Kress and van Leeuwen (1996) use the term 'photographic naturalism' to explain the composition of photographs of objects, where their composition is intended to create an illusion of touch, taste and smell, in images of food for example, where the actual food may be inedible in reality but is arranged and treated in such away that it produces an emotive response. This is an example of representation as design. The photograph is designed to produce an emotive response to the food depicted by the use of compositional juxtaposition and practical devices, such as glazes and solid carbon dioxide, to imply texture and smell.

In addition to aspects of physical composition within the frame, depth cues in terms of shadows and bright areas enable the viewer to determine the spatial orientation of objects and subjects depicted. Experience of viewing objects and knowledge of their reality will guide interpretation. Photographs of people, for example, will be interpreted from knowledge of seeing real people in differing contexts. The effort made to interpret the depth cues of light and shadow is minimalised given the inherent knowledge of the appearance of the human form. Only when a person is depicted in unexpected circumstances will the actuality be examined and an attempt made to interpret what is seen (Mirzoeff 1999).

Photographs of objects are more difficult to interpret in terms of depth cues. The appearance of the object can be distorted by the contrast of light and shade and the angle and distance of image capture. Theories of visual perception suggest that in this circumstance, the viewer will attempt to make sense of what is seen using experience of previous viewing experiences. So, though a photograph may imply authenticity and authority of content the reality may be different (Gombrich 1972, Jenks 1995).

Photographs may be used in isolation but are more commonly included in other forms of representation such as books, posters or even animations. Their use as representational material may imply an air of authority and sense of reality (Sturken and Cartwright 2003) which may not be appropriate. The way in which they are used in lessons may have a mediating effect on these impressions. If photographs are used in combination with other images, these images are likely to be drawings or a diagram, offering other interpretations of what is depicted in the photographic image.

Unlike photographs, diagrams are not regarded as instances of reality. Rather they are seen as working drawings to articulate thoughts about objects, processes or systems. They are not intended to show the actuality but to denote meaning by relating lines, dots and blobs to aspects of reality (Tversky 1985).

2.8.3.6 Diagrams

Diagrams are a common way of illustrating science texts, particularly in books for older children and adults. Traditionally, diagrams were used in science textbooks as working drawings to depict observations. They contained only observable elements and as such appeared relatively simplistic in comparison to illustrations or photographs. Diagrams which are produced without embellishment convey the reality of the situation, as would be observed by anyone repeating the exercise, in the case of botanic, zoological or engineering drawings (Lapage 1961, Hartley 1994). In physics diagrams, traditionally equipment was shown in outline, so as not to detract from the other information, such as the direction of forces or rays of light, which formed the main emphasis of the diagram (Hartley 1994).

Diagrams may require some form of explanation before all aspects represented become clear to inexperienced viewers, because they may not contain all elements of the real situation, or may contain them in outline. Often these explanations are intended in accompanying text passages or, in some cases, an oral explanation (Tversky 1989, Hartley 1994).

Traditionally, diagrams in scientific texts consist of lines, usually black, to outline the pertinent components of objects (Pintó and Ametller 2002). Solidity may or may not be indicated by blocks of colour, usually black, or shading as some form of hatching, showing the major relevant parts of the system in their relative positions. In addition to lines and areas of concentrated shading there may be other types of notation used, commonly arrows, to denote movement (Tversky *et al.* 2000).

If the scientific phenomenon being illustrated is a system which involves relative movements in both space and time, then not only do the parts of the system have to be correctly interpreted but the information intended by any arrows has also to be correctly interpreted. Gombrich (1990) has noted that arrows denoting movement appear not to have been used prior to the 18th Century. Tufte (1990) describes how depictions of movement in space and time drawn by early astronomers were achieved by repeated images instead of arrows.

Tversky *et al.* (2000) suggest that arrows can also denote causal sequences of movement and their research shows that students observing diagrams with and without arrows added put forward different interpretations. The students who had diagrams with arrows implied causal sequences of movement when describing the diagram whereas the student viewing diagrams without arrows gave purely structural explanations of what they saw (Tversky *et al.* 2000). Understanding the meaning of arrows in drawings and diagrams is dependent on the viewer correctly identifying all the other parts within the image. Tversky (1989) suggests that the parts of images will tend to be grouped in such a way that they make conceptual sense based on knowledge of other objects which have a similar appearance. If arrows are introduced, knowledge of the function of the parts may be necessary to fully comprehend the meaning intended. A curved arrow outside a circle could denote either movement about an (invisible) axis or linear movement out of or along the page. It is difficult to know the intended meaning if there is no context. If the circle is given a context then the movement denoted by the arrow is more likely to have meaning. In the case of arrows indicating orbital direction or planetary rotation, there is room for confusion if the context is not clear, consequently leading to misunderstanding of the way in which bodies in the Solar System interact in terms of yearly and daily cycles which result in the phases of the Moon and the occurrence of seasons.

Stylianidou *et al.* (2002) found that arrows used in some diagrams actually had more than one function, depicting movement, direction and energy changes in a single diagram. They found that children were confused as to the intent of the arrows as the different meanings of the arrows led to different interpretations of the diagrams they were shown. Arrows placed without due consideration of the impact they have on the interpretation of an image or illustration can provide misleading information, which if not made clear by explanations, could then be incorporated into an individual's mental model as a misunderstanding. The different sizes, forms and positions of arrows are likely to cause confusion if not adequately explained, hindering interpretation of the diagram (du Plessis *et al.* 2002).

Diagrams may be created as part of an explanation and therefore be working drawings, where some elements are implied or given explicitly as part of the verbal explanation. When diagrams on the board intended for reproduction by children in their exercise books to be looked at, at a later date for revision purposes are drawn without discussion or explanation, the potential for constructing meaning from them is likely to be limited. However, diagrams are useful visual tools. They can represent large amounts of information with just a few lines. Interpreting diagrams drawn by others requires knowledge of the conventions of diagrammatic drawing, using arrows to represent movement, for example. If parts of the diagram contain signs and symbols unintelligible to the viewer, it is unlikely that it will be validly interpreted (Lister and Wells 2004).

The use of diagrams as representations in science lessons presupposes the question of the reason for selection over other forms of representation. If the diagram is seen as a simple, clear and unambiguous representation of a whole or a part of a system, those reading the diagram need to understand the use of conventional signs used in the diagram. If the diagram is a teacher's interpretation of a whole or part of an object system or event, they will construct it using their own knowledge which again presupposes that they feel that this is the best form of representation available at that time, and that it is sufficient for its purpose. Diagrams may be combined with other forms of representation, in which case the aspects of the diagram that are included or excluded in the drawing of the diagram may give an indication of both the teacher's knowledge of the phenomenon and the knowledge they feel the children should have.

The effect of books depicting science principles and phenomena and their accompanying images are therefore open to differential interpretation depending on their format, leading to potential difficulties in meaning making from them. If the phenomena represented cannot be fully experienced in reality, such as the Earth in Space, then the potential for revision of misunderstandings is lessened. There are a number of areas within this topic where misunderstandings have been identified by research (Nussbaum 1979, Jones *et al.* 1987, Baxter 1989, Osborne *et al.* 1994). The tenacity of the misunderstandings can be such that they persist into adulthood, despite teaching interventions, and are an indication of the complexity of the knowledge required for understanding (Mant and Summers 1993, Parker and Heywood 1998). Therefore, it is likely that some teachers will hold misunderstandings of the phenomena they teach. Knowledge and understanding of the common misunderstandings potentially held and possible intervention strategies to address and resolve them implies that teachers need to know the extent of their own areas of misunderstanding and are prepared to acknowledge and address them.

2.9 Classroom context for the use of representations

2.9.1 Earth in Space topic

The topic selected for testing against the research questions was the Earth in Space as it specifically related to the series of lessons in the study school. The school followed the Earth in Space topic of the National Curriculum for England and Wales (DfES 2005) described in Physical Processes (Sc4). This topic also features in many other countries' school curricula and therefore the understanding of children's ideas about aspects of the topic and the way they learn has important international relevance (Mali and Howe 1979, Vosniadou and Brewer 1992, Fang 2005).

Astronomy concepts are regarded as difficult to understand and to teach (Mant and Summers 1993, Parker and Heywood 1996, Vosniadou 1997). The notion of difficulty arises from two perspectives, firstly the perceived difficulty of physics as a science subject and secondly the counterintuitive nature of certain scientific explanations in comparison with personal experiences and observations. It is also a topic where many misconceptions, resulting from personal observations, are held by both adults and children. Teachers who are unaware that their understanding contains misconceptions are liable to pass them onto the children they teach (Sadler 1987, Barba and Rubba 1992, Schoon 1992).

However, the Earth in Space is a very popular topic with both teachers and children (Sizmur and Ashby 1997). Children appear to enjoy thinking and talking about the larger aspects of space, planets, stars, spaceships and possible aliens. Teachers also seem to enjoy teaching the subject, possibly because of the amount of interest and enthusiasm shown spontaneously by the children. However, these aspects are not specified in the current curriculum documents for Key Stage 2. Those topics actually specified are the shape and relative sizes of the Earth, Sun and Moon and mechanisms involved in the occurrence of day and night, relatively limited in comparison to the apparent interest of both teachers and children (Sizmur and Ashby 1997, DfES 2005). Aspects of the topic, the occurrence of day and night for example, may appear to be relatively simple because they are directly observable. Understanding the relative sizes of the Earth, Sun and Moon, may present difficulties as the actuality differs from what is directly observed.

The content of the topic is clearly defined, but many teachers include material which is not specified, such as seasonal change and the phases of the Moon. There are a number of possible reasons for this including, changes to the curriculum which may not have been integrated into the science planning, the interest shown by children in the topic of space and the apparent simplicity of some elements of the topic.

2.9.2 Earth in Space in the Science Curriculum

2.9.2.1 Status in the Science Curriculum

In 2000 the Science Curriculum was revised with new orders produced for implementation. There were changes to the Earth in Space topic of the Physical Processes Sc4 Programme of Study with seasonal change and the phases of the Moon no longer being a required element for the Key Stage 1 (ages 5 - 7 years). Aspects of light and dark with emphasis on the formation of shadows as being the absence of light are now required study topics, which continues at Key Stage 2 (ages 8 – 11 years) where the formation of shadows is studied in more detail, relating it to the movements of the Earth relative to the Sun and the occurrence of day and night. In Year 5 (age 9 – 10 years) the children address the topic of Earth, Sun and Moon. Although the phases of the Moon are not mentioned specifically in the Programme of Study, in the section of possible activities suggested (QCA 5e 1998), mention is made of the use of secondary sources to "illustrate that the appearance of the Moon changes in a regular manner over a period of approximately 28 days". Seasonal change is not mentioned until the Year 7 Programme of Study at the beginning of Key Stage 3 (ages 11-14 years).

Though the content of all subjects is governed by the National Curriculum, and the Qualifications and Curriculum Authority (QCA) provides guidance for activities, teachers may not always adhere strictly to these recommendations, adding material of their own. The reasons for this may be partly historical in that school or personal teaching plans have not been updated in line with the many curriculum changes.

2.9.2.2 Required knowledge for teachers

Trainee teachers are required to have a secure knowledge and understanding of all topics in the science curriculum (DfES/TTA 2003). The original documentation specifying knowledge for trainee teachers Circular 4/98 (DfEE 1998) was superseded by Annexe E (1) which states what trainee teachers should know.

This document has now been superseded by the Handbook for Guidance (DfES 2005) which does not specify any actual content knowledge, but reiterates that trainee teachers should have knowledge and competence in all aspects of the curriculum they are to teach. The requirements of Annexe E (1) are beyond the scope of curriculum content and cover areas where it is known that some teachers feel uncomfortable in their subject knowledge (Vosniadou and Brewer 1992, Mant and Summers 1993, Summers and Mant 1995, Parker and Heywood 1998). The inclusion of such depth of detail during training and the historical development of curriculum content is possibly why some teachers continue to include seasonal change and the phases of the Moon, in addition to any relevant astronomical events such as eclipses or passing comets, in their teaching at Key Stage 2. There is also a case for suggesting that the demands of the curriculum with its emphasis on causal explanations of day and night implicate notions of the Earth's rotation and its orbital path around the Sun, which in turn implies explanations of seasonal change (Parker and Heywood 1998). There appears therefore to be some confusion as to the extent of the knowledge required by training teachers and the extent and limit of the curriculum document for children's knowledge. The indication from the guidelines for trainee teachers suggests that their course will cover appropriate material and therefore have opportunities to address any misunderstandings they may have.

The pedagogical emphasis of the government documents relating to teacher training and continuing professional development increasingly support a constructivist philosophy for teaching and learning. The importance of children's ideas and the use of appropriate questioning techniques to establish these initial ideas are stressed. The use of consensus and teaching models to support inaccessible phenomena is encouraged. Teachers are expected to know about scientific models and their use in the formulation and testing of ideas in scientific communities. The importance of discourse as a tool for promoting exchange of ideas between individuals, in small groups and whole classes is encouraged (DfES 2005). In order to facilitate this learning environment teachers need a secure conceptual understanding of the topics they are to teach.

One problem with the Earth in Space topic is that it is regarded by teachers as a difficult topic, both to understand and to teach, despite the apparent simplicity of directly observed events. Physics as a subject has long been regarded as complex and difficult, causing lack of uptake of the subject at school amongst girls particularly (Whyte 1986, Murphy 1997, Marsh 1998). As the majority of primary school teachers tend to be female, the perceived difficulty of physics and associated topics, such as the Earth in Space, may result from their perceptions of science. Whatever the reason, there is evidence to show that teachers are not confident in their understanding of the concepts (Mant and Summers 1993, Parker and Heywood 1998, Taylor *et al.* 2003, Peacock and Miller 2004).

The current scientific consensus of explanations for the phenomena encompassed by the study of the Earth in Space contains concepts requiring knowledge of the relative movements of spherical bodies, the effect of light striking spherical bodies, the angle of incidence of light and the effect of rotation and orbit on all of these. An underlying appreciation of the effect of gravity on planetary bodies is useful but not referred to by the curriculum for Key Stages 1 and 2. The scientific knowledge and explanations required to understand the phenomena included in the Earth in Space topic, which are outlined in Appendix I, are relatively extensive and not necessarily made explicit by the descriptions in the curriculum documents. Misunderstandings may occur on the part of the teacher when this scientific knowledge is inaccurate or incomplete. The likely prevalence of these misconceptions amongst primary school teachers (Mant and Summers 1993, Parker and Heywood 1998), which are elaborated upon in Section 2.10, and is fundamental to the formulation of the research questions presented in Section 2.12.

Difficulties with the topic arise from scientific explanations that are neither directly observable from our position on Earth nor straightforwardly intuitive and therefore require an understanding of the relative movements of spherical bodies. On the other hand the movements of the Sun and Moon and seasonal variation are directly observable and individuals will form their own explanations for what they see. Their mental models may contain accurate aspects, but generally, their expressed models of the movements of the Earth, Moon and Sun and seasonal change contain misunderstandings. These misunderstandings have been subjected to numerous research studies (Nussbaum 1979 and 1985, Jones *et al.* 1987, Baxter 1989, Schoon

1992, Vosniadou and Brewer 1994, Kikas 1998, Sharp 2003, Sharp and Kuerbis 2006) which have identified commonalities in the misunderstanding of the major aspects of the Earth in Space topic.

2.10 Common misunderstandings in the Earth in Space topic

The emergence of the notion of school or children's science (Gilbert *et al.* 1982) gave rise to numerous studies regarding the precise nature of children's understanding of scientific phenomena. These have been usefully collated in a bibliography by Helga Pfundt and Reinders Duit (1991) providing a seminal reference point for all areas of the science curriculum, for teachers and researchers. The notion of misunderstandings has been addressed in general terms previously, but here the misunderstandings relating to the topic of the Earth in Space will be specifically discussed because they relate to the aspects of the curriculum taught in the study school.

2.10.1 The Solar System

Many children are able to recite the names of the planets in the Solar System; even very young children are quite often able to recite them in order from the Sun (Sharp 2003). Knowing the names of the planets does not necessarily mean that the children appreciate the structure or relative sizes, distances and movements of the planets. A number of variations in the structure of the contents of the Solar System have been observed in children (Baxter 1989, Sharp 1996 and 2003, Marsh *et al.*1999) ranging from Earth-centred random representations of all the planets to Sun-centred 'processional' representations.

One feature most children's linear or processional representation drawings have in common is that the order of the planets is correctly represented. Indications of relative sizes and distances are rarely represented, though this could, at least in theory, be more to do with difficulties in drawing rather than lack of knowledge. Stars are often included in the lists of objects within the Solar System (Mant and Summers 1993, Summers and Mant 1995, Selley 1996, Lemmer *et al.* 2003), with confusion as to the precise nature of what constitutes a star being common. There is thought to be a progressional development in ideas about the structure of the Solar System though this is by no means as clear cut as in other areas of children's ideas about Earth in Space phenomena (Sharp 2003, Sharp and Kuerbis 2006).

2.10.2 The Earth

The notion that the Earth is a spherical body is one of the initial learning objectives of the Earth in Space topic. It is difficult to appreciate the spherical nature of the Earth from many points on Earth's surface, the predominant perception being that of the Earth stretching to the horizon; essentially flat except for surface features of mountains and valleys. The curvature of the Earth is only visible from extremely high points on the Earth's surface and is actually dependent on knowledge of its curvature to interpret what is then seen.

Children who believe that the Earth is flat often also suggest that it is circular in shape, suggesting that representations of the Earth are interpreted as a 2-dimensional shape, such as a disc (Nussbaum 1985, Vosniadou 1997). An understanding of the spherical nature of the Earth is critical for comprehension of many other observable phenomena, such as dawn and dusk and time variations over the Earth's surface. The shape of the Earth is implicated in the comprehension of more complex notions such as the operation of the force of gravity (Nussbaum 1979). Nussbaum suggested five notions which he found were commonly held which have not currently been superseded. The five notions record ideas about the direction of gravity in addition to the children's view of the shape of the Earth, and surmise that the ideas go from an egocentric notion through increasing conceptual awareness and development until the spherical notion is reached.

Further studies showed that alternative concepts about the shape of the Earth existed and revealed that children initially hold the ancient flat Earth perception (Sneider and Pulos 1983, Schoon 1992, Vosniadou and Brewer 1992, Arnold *et al.* 1995). This notion appears to be generally held and culturally independent (Mali and Howe 1979, Klein 1982, Sharp 1996 and 2003, Vosniadou 1997). Gradually in time and with increased experience gained from a variety of sources including teacher input, this notion changes to become that of a spherical Earth. Initial, naïve ideas will only be superseded as cognitive development decreases the level of egocentricity, facilitating a wider world view (Donaldson 1978, Mali and Howe 1979, Roald and Mikalsen 2000).

Vosniadou (1997) supports this view of cognitive development of concepts regarding the Earth's shape. Models she has termed 'synthetic' models are created by children as they encounter information that indicates that there may be flaws in their initial model, but are unable to rationalise a spherical model with their experience of a flat Earth surface. In time the synthetic model develops into the scientific model and the Earth is known to be a sphere, even when it is represented as a circle in diagrams and illustrations. Though these conceptual developments correlate to an extent with age and therefore cognitive maturation, experience is also a factor, with children from more rural, technologically impoverished or non Western backgrounds holding naïve notions for a longer period of time (Mali and Howe 1979, Klein 1982, Sneider and Pulos 1983, Lemmer *et al.* 2003). Once the notion of a spherical Earth is cognitively embedded, it is difficult to appreciate that a flat Earth is conceivable,

2.10.3 The Earth, Sun and Moon system

The Earth-Sun-Moon system whilst part of the curriculum for science is also an integral part of a child's daily observed world. Conceptual understandings about the relative sizes, distances and movements of the three bodies show a conceptual progression moving from Earth-centred movements to Sun-centred movement. Common misconceptions about the presence or absence of both the Sun and the Moon are related to an understanding of the Earth's spherical shape and the movements of the Sun and Moon relative to the Earth. The relative sizes of the Earth, Sun and Moon are difficult to conceptualise as the Sun and Moon can appear to be the same size as each other and both appear to be smaller than the Earth. The distances between the three bodies are obviously larger than anything that can be experienced on Earth and to show children physical models of the system relies on the fact that their conceptual development has reached the stage where they know that the three bodies are spherical and they are able to appreciate the implications of scale (Jones *et al.* 1987, Sadler 1987, Marsh 1997b). If children hold an egocentric view of the system, which is Earth-centred, this will impede their ability to conceptualise a heliocentric representation, and therefore begin to develop the consensual scientific concepts (Jones *et al.* 1987, Sharp 2003, Sharp and Kuerbis 2006). Direct observation of the Sun and Moon leads to the notion that the Earth is central to the Earth-Sun-Moon system due to the appearance of the movement of the Sun and Moon, as they pass daily across the sky (Hellden 1997, Lemmer *et al.* 2003). Vosniadou and Brewer (1987) suggest that this "can only be a partial analogy" (p58) due to the children's exposure and access to modern media and as children will listen to the myths and watch animated representations they form their own interpretations, a combination of what they observe in reality and information they receive from other sources.

Jones *et al.* (1987) found that there were a number of variations in ideas about the spatial arrangements of the bodies starting from two variations of a geocentric model to variations on a heliocentric model. These ideas were confirmed by a study by Selley (1996) who found that the geocentric notion was held by younger children (Year 3) developing into a heliocentric model in older (Year 7) children. Osborne *et al.* (1994) suggest that the geocentric notion of the Earth-Sun-Moon system arises from direct observation but is readily superseded by teaching the scientific notion. Vosniadou and Brewer (1987) regard the change from a geocentric notion to a heliocentric notion as requiring 'radical restructuring of knowledge' which can be achieved through appropriate teaching intervention. These misunderstandings have been found to exist in countries with different cultures and appear to follow the same progression despite the differing cultural beliefs, implying that direct observation informs mental model formation of astronomical events (Kikas 1998, Trumper 2001, Lemmer *et al.* 2003).

In conjunction with ideas about the movements of the Earth, Sun and Moon are notions related to their relative sizes. Direct observation of the Sun and Moon from the Earth indicates that they are smaller than the Earth and of similar sizes. Studies enquiring into children's ideas about the relative sizes of the bodies have found that initial ideas are of three similar sized bodies in close proximity (Jones *et al.* 1984, Sadler 1987, Osborne 1994, Marsh 1997b). Whether these ideas change in step with the conceptual move from a geocentric to heliocentric Earth-Sun-Moon system is not known.

2.10.4 Seasonal change

The most common misunderstanding about the way the seasons are caused is that the Earth is tilted towards or away from the Sun, suggesting when the Earth is tilted away from the Sun it is winter and in summer the Earth is tilted towards the Sun. These ideas are based on experiences of heat sources (Baxter 1989, Sharp 1996). This knowledge of heat sources suggests that summer and winter heat changes are caused by the Earth being tilted towards or away from the heat source, the Sun, and therefore we feel more or less heat energy (Baxter 1989, Trumper 2001).

As knowledge increases and the concept of a tilted Earth is integrated into knowledge structures, the notion that the Earth is nearer the Sun reinforces the proximity to a heat source concept. The actuality is in fact the absolute opposite, with the Earth being further away from the Sun in the summer, due to its off-centre elliptical orbit.

Baxter (1989) suggested six notions prevalent among children about the reason for seasonal change, ranging from planets absorbing heat from other planets and the Sun, to distance from the Sun and cloud cover. The sixth notion involved knowledge of the tilt of the Earth in relation to the Sun. Mali and Howe (1979) also found a distance from a heat source explanation in the Nepalese children she interviewed. These results give the impression that the distance factor is the main causal concept for seasonal change, irrespective of Earth's axial tilt. Sharp (1996 & 2003) found the most common concept for seasonal change held amongst the group of Year 6 (10-11 years) children he interviewed was the tilt of the Earth, but rather than an accurate reason given for the tilt being causal, they suggested that the tilt caused the Earth to be closer/further from the Sun, therefore affecting heat energy reaching the Earth (Sharp 1996 & 2003, Sharp and Kuerbis 2006).

The explanations found by Sharp (1996) and Mali and Howe (1979) deal with the variation in temperature of the seasons and occasionally the variation in light, though is not often mentioned. The explanations do not mention the varying position of the Sun in the sky or the changes in day length. Though changes in day length may occasionally be mentioned as a feature of seasonal change, explanations as to the cause are cloud cover and bad weather in the winter months (Sadler 1987, Baxter 1989, Summers and Mant 1995). Other factors that are implicated as causal in seasonal change are physical factors such as the growth or lack of growth of plants (Baxter 1991, Kikas 1998) suggesting direct observation of the physical environment. Again, Baxter (1989) suggested that there was a progressional development in children's explanations for the reasons for seasonal change starting with a cloud cover explanation and moving towards a notion that implicates the angle of the Earth to the Sun.

2.10.5 The phases of the Moon

The most common misunderstandings about the phases of the Moon, held by both adults and children, are that the different shapes are caused by the shadow of the Earth, or by clouds covering the Moon (Jones *et al.* 1987, Barnett and Marron 2002). The Moon is also thought to have a constant, planar orbit around the Earth's equator, which would in reality result in a lunar eclipse every month, as the Moon moved between the Earth and the Sun.

The Sun and Moon appear to be similar sizes in our skies, sometimes leading to the notion that either the Moon is very large, derived from existing knowledge of the size of the Sun, or that the Sun is relatively small. These misconceptions can affect perceptions about the occurrence of the phases of the Moon. The daily appearance and disappearance of the Sun and the Moon, and the occasional appearance of the latter in the daytime sky, have also been implicated as being instrumental in the formation of ideas about the phases of the Moon, mainly in terms of shadows being caused by either the Earth or cloud (Baxter 1989).

A progression in ideas about the phases of the Moon was proposed by Baxter (1989) where the causal reasons moved from cloud shadows to Earth shadows to a more or less complete understanding of the inter-relationship between the Earth, Sun and Moon. Sharp (1996) found that children held one of six 'constructs' about the causal factors of the phases of the Moon, from intuitive ideas involving cloud cover to combinations of intuitive ideas and taught ideas, which he termed synthetic models, through to the scientifically agreed explanation of the relative movements of the three bodies.

2.10. Addressing misunderstandings about the Earth in Space

Originally identified as children's science (Gilbert *et al.* 1982) and identified by Driver *et al.* 1994) as prior conceptions, consideration of children's misunderstandings about aspects of phenomena in the science curriculum now form part of the planning for many lessons and are recommended in the advisory documentation provided by the government for initial teacher training and professional development programmes (DfES 2005). The common misconceptions about the Earth in Space have been gathered together in 'Concept Cartoons' developed by Keogh and Naylor (2002) which provide a valuable starting point for discussions in the classroom.

It may be considered difficult to illustrate the behaviours and mechanisms of the bodies and occurrences in the Solar System and the Earth, Sun and Moon system due to the difficulty in providing activities for the children to test their ideas. It is possible to provide such activities as has been demonstrated by the SPACE project (Osborne *et al.*

1994), the Earth and Space project (ASE 1990) and in materials produced for trainee teachers (Mant 1993, Selley 1996). All provide ideas for activities which engage children in expressing and questioning their ideas, promoting resolution of conceptual challenges which is likely to be coherent and durable (Posner *et al.* 1982, Hewson *et al.* 1998, Ashcraft and Courson 2002).

The ideas about all the aspects of the Earth in Space outlined above show a number of different ideas that appear to be generally held by children and some adults. These ideas have been identified by Vosniadou (1991) as being intuitive, synthetic or scientific depending on the level of conceptual understanding demonstrated in explanations. Moving from a naïve, intuitive conceptual perspective to a scientific conceptual perspective requires careful restructuring of personal conceptual frameworks (Vosniadou and Ioannides 1998) and is potentially determined by age-related cognitive development (Baxter 1989).

Initial misunderstandings relate mainly to structural and physical aspects of the bodies in the Solar System (Jones *et al.* 1984, Sadler 1987, Sharp and Kuerbis 2006). The behaviours and mechanisms of astronomical phenomena, though important for complete understanding of everyday occurrences, are often glossed over or ignored completely in representational materials. The behaviours and mechanisms operant between the bodies in the Solar System are difficult concepts and not absolutely necessary for understanding the structure of say the Solar System, but without knowledge of the behaviours and mechanisms, some phenomena, such as seasonal change and the phases of the Moon, will not be explicable and misconceptions will persist unchallenged. The choice of representational material and the way it is used in lessons has important implications for knowledge construction, particularly in those topics which are recognised as cognitively difficult (Ashcraft and Courson 2002, Barnett and Marron 2002, Fang 2005).

2.11 Summary

Teaching and learning in primary science classrooms have undergone huge changes in both content and process. Theories of teaching and learning have evolved, focussing on the child as an active participant in the construction of their own knowledge with the teacher as a facilitator rather than a transmitter of facts. The role of the teacher as a facilitator involves awareness of their personal knowledge, their understanding of the way children learn and the way they engage children in learning in the classroom. It also potentially has implications for the materials they use in their lessons.

2.11.1 Teaching and learning in science

The current government recommendations for pedagogical practices in primary science classrooms stress the importance of the knowledge children bring to their science lessons, of discussion for expression of these ideas and engagement in appropriate activities to encourage the reconstruction of incomplete or inaccurate ideas (DfES 2005). A teacher's pedagogical practice results from their understanding of how children learn and therefore how they think knowledge is acquired by learners. The methods a teacher uses to engage children and encourage their learning must therefore be important factors in any enquiry into learning in the science classroom.

If children's ideas are not known or elicited, teaching starts from the teacher's rather than the children's perspective. The potential for the retention or creation of misunderstandings is increased if the learner's ideas are not taken into account. Constructing knowledge from initial mental models ensures that children are able individually to restructure their understanding, taking into account new knowledge and experiences, to form new concepts and understanding.

Representational materials used in primary science classrooms to illustrate aspects of topics in lessons require interpretation by both children and teachers. Interpretation, reading of the materials, requires visual literacy skills which are not normally considered or taught in schools (Mayer *et al.* 1996, Unsworth 2001). Opportunities for children to discuss their ideas about the representations used will not only elicit their own understandings but will highlight similarities and differences between individual representations. This indicates that the type of representational material selected for use in science lessons is likely to be important and needs to be sufficiently engaging and relevant for the children to respond to.

2.11.2 Representations in the science classroom

An integral part of the methods teachers use to engage children with learning in the science classroom must be the materials they select. If these are cognitively appropriate and accessible to the children, they are likely to encourage accurate and meaningful construction of knowledge. However, if children are unable to decode the visual material presented to them, whether this material is in the form of images or concrete models, they will make little sense of what they see and opportunities for challenging misunderstandings may be missed if children are unable to engage with material on either a cognitive or perceptual basis.

Representations are useful tools in any science classroom and are widely used in some format. However, the decoding skills required to interpret visual material are probably underestimated. There is no doubt that children will construct meaning from any visual experience. But the quality of their interpretation and therefore the meaning constructed from any representation is likely to be dependent on the teacher's awareness of the task inherent in complex reading of visual material, the use the teacher makes of that material and the way in which children interact with the material. This is a facet of classroom practice that is often overlooked, giving rise to the need for further research in this area.

Knowledge of the conceptual content and the likely interpretation children might make of representational materials will assist explanations of scientific phenomena by suggesting areas and aspects of the representations which need to be highlighted or made explicit, by including the use of gesture and explanation to enhance understanding (Crowder and Newman 1993). It also will allow insight into children's alternative explanations if opportunities for interrogation of and discussion about the representational material are made possible (Buckley and Boulter 2000). So the question of what types of representation teachers select for use in a potentially challenging topic such as the Earth in Space is significant. Similarly, the amount of use teachers make of representations may also influence children's willingness and ability to engage with them, therefore potentially affecting their use in the science classroom. If individual representational objects are used for more than one purpose this may cause confusion (Norman 1983, Clement 2000).

The initial choice of representational material is possibly determined by the teacher's personal knowledge of the phenomena being studied and the availability of materials. The use teachers make of available materials may determine their efficacy as tools for constructing meaning, engagement with learning and addressing misconceptions and will affect the durability and transferability of any new knowledge constructed.

Overall, the use of representational materials as tools for teaching and learning and therefore their contribution to knowledge construction in the primary science classroom appears to be important and relatively under researched. Factors underlying the use of representations for the construction of knowledge almost certainly include the teacher's pedagogy, personal knowledge of the subject, understanding of the way learn occurs, particularly in science, and their understanding of the way visual objects and images are constructed and viewed.

2.12 Formulating the research questions

The review of the literature highlights the following key factors which appear to be important in the use of representations in science classrooms:

1. the teacher's understanding of how learning takes place
2. the teacher's knowledge of the phenomenon in question
3. the teacher's knowledge of possible misconceptions about the phenomenon
4. the way in which visual materials are constructed
5. the teacher's understanding of how visual material is viewed and interpreted
6. the use of explanations and gesture in this process
7. the effect that interacting with visual material has on the construction of knowledge.

In response to these areas highlighted by previous research, the following general questions were formulated:

1. What type of representations do primary science teachers select?

2. How are these representations used in lessons?

3. Do the representational materials present a cognitively coherent pathway to facilitate the construction of knowledge by the pupils?

In order to answer these general questions a study was designed that would follow a specific teacher and their class for a whole series of lessons on one topic of the National Curriculum for Science, as it was taught in the context of the whole school's science curriculum. The development of the research questions specific to this teacher and their class, the design of the study and the methods used to investigate these questions are described in Chapter 3.

Chapter 3

Methodology

3.1 Introduction

The literature review discussed in the last chapter gave rise to the general questions about the use of representations in the science classroom:

1. *What type of representations do primary science teachers select?*
2. *How are these representations used in science lessons?*
3. *Do the representational materials present a cognitively coherent pathway to facilitate the construction of knowledge by the pupils?*

This chapter will discuss and justify the decisions that were taken in making these general questions specific to a particular teacher and a particular teaching sequence.

3.2 The design of the study

As I was engaged in home tutoring and supply teaching during the likely period for fieldwork, the possibility of conducting an action research study into my own practice, as I had done on previous occasions, was limited as I could not guarantee that I would have access to a science class for the duration of the fieldwork. I was interested in seeing how representations are used in the science classroom. I felt this could only be achieved by observing reality in a normal primary science classroom setting. Having limited access to a science class myself, the next best option was to 'borrow' a class of children and a teacher I had already worked with. This would be almost as natural a setting, in which I could observe the use of representations as this occurred in the lessons, and little influenced by external factors, such as unfamiliar people in the room.

Other methods which could have been used to gather the data were considered too intrusive for a primary science classroom or too impersonal. Survey methods, such as questionnaires, would not have allowed me to see the way different types of representations were actually used in the classroom as reported by teachers. A large scale questionnaire study would have involved very little contact with teachers. A smaller scale, more in depth questionnaire study conducted with staff members would have required large amounts of staff time for it to be completed. Personal knowledge of a normal school day suggested that this would be quite an imposition for any staff involved. This combination of factors led to the decision to conduct a study in as unobtrusive and non-invasive manner as possible.

My experience as a primary science teacher gave me an insight into questions it would be feasible to answer in the context of the primary science classroom and also into the methodologies which were likely to be appropriate and practicable in such settings. I was anxious to minimise disruption and difference for both the teacher and the children. My position as an insider researcher allowed me to know what effect research practices were likely to have in the science classroom. It also allowed me to know to some extent how a teacher might feel about their practices being scrutinised and how children were likely to react to a 'stranger' in their classroom. Methods that would cause a minimum impact were considered in the first instance.

The investigation of the questions could be formulated in a number of ways. For example, answering the questions could be achieved by following one lesson taught by a number of teachers, either in the same school or in a number of schools, and observing the number, type and method of use of representations in those lessons. Observing a number of teachers using representations would give an overview of the types and uses of representations, in a variety of settings. For the purposes of comparison, the same lesson topic would need to be accessed. However, it is possible that not all science topics would involve the use of representational material, even at primary level. A direct comparison from which valid conclusions can be drawn requires the same or very similar study situations. Studying a single lesson in a number of schools would require access to be negotiated with several different groups of people. Though I have extensive experience of teaching primary school children generally, and teaching primary science in particular, I did not consider the number of schools where I was sufficiently well known by current pupils and staff would provide a large enough sample for the observation of one lesson.

Observation of teachers using representations could involve one lesson or a number of lessons. Observation of one lesson would give an insight into how representations were employed in a single scenario. This would not give access to information about how representations are used more widely in science lessons. Observation of a number of lessons would permit insight into how representations are used over a period of time.

One teacher could be observed teaching a whole series of lessons and the type and use made of representations noted. This would be useful, in that it would allow an insight into the amount of use a teacher makes of representational material over a series of lessons and give an insight into the contextual aspects of representational use.

If a single teacher, teaching a whole topic of science lessons, was the focus of the study, then the different types of representation selected and the way they were used in the development of the topic could be accessed. This would give a contextual basis for the use of representations during teaching. Studying several teachers teaching the same topic would not give this level of detail, in that the contextual aspect would not be as visible as in a single setting. So it was decided to make a single teacher, teaching a science topic, the focus of the study.

Studying a single teacher teaching a science topic could be accomplished in a number of ways. A questionnaire would collect data about the types of representations used. This would not give detailed information about how they were used, nor the context in which they were used in lessons.

Interviews with the teacher could be used to ascertain the types of representations used and the way they were used. But again, unless the teacher was observed using representations, the contextual aspect would only be that reported by the teacher in the interview, which may not reflect reality. Structured interviews would mean that the researcher's questions were addressed, but might not probe deeply enough into the teacher's personal feelings about the selection and use of representational material. The data collected from structured interviews, as with questionnaires, would not reveal any contextual issues of representational use. A semi-structured interview would give the opportunity for expression of personal ideas and views, which may not have occurred to the researcher. Contextual information would still be absent, except as reported instances. Direct observation of contextual information about the use of representations is an important part of understanding the nature of their involvement and significance in teaching and learning.

Therefore, it was decided, ethnographically, to follow one teacher for a whole series of lessons on one science topic. Using a case study approach allows an in depth study within a bounded system and requires multiple sources of information to contribute to data collection (Cresswell 1998). In this case the setting, the bounded system, would be a series of science lessons on a single topic taught by one teacher in a primary science classroom. Though this would limit the generalisability of any findings, it would provide an in depth view of a single teacher using representations in a series of science lessons in an area of classroom practice that appears to be under researched.

Consideration was given to the possible methods of data collection which would be feasible in a primary science classroom, but the actual methods were not finalised until the study school and the prospective participants had agreed to take part.

3.2.1 The study school

The study school, Southfield, (a pseudonym) was one of a number approached on the basis of previous teaching association. In this way the head, staff and children would be familiar with the researcher. The fact that the researcher was known to all participants, would to an extent mitigate the presence of the researcher and the research activities in the study in the school, by minimising differences and disruptions to normal routines, so allowing observation of classroom activities to be as naturalistic as possible. Previous personal research experience in schools had indicated that my position as a teacher researcher was important to me, in the first instance because it reduced the pressure of 'performance' for the participants, in that research activities could be conducted as part of the normal classroom routine. And secondly, as a methodological issue as I would be conducting a naturalistic study in a familiar setting, giving me advantages of timing, in that I did not have to spend large amounts of time for the children to become familiar with my presence or for myself to understand the teaching situation and all its nuances.

Southfield was an independent school, catering for children from 3-18 years of age, in a suburb of London. The school supports and has interests in educational research and the study teacher volunteered to participate. The school head requested that they negotiate participation permissions with the children and their parents on behalf of the researcher. In addition, the researcher discussed the project with the study group of children outlining the focus of the project and what their participation would involve.

3.2.2 The case

Once the school had agreed to participate, the teacher selection was considered. Constraints of national testing in schools usually reduce the available pool of participants. In addition, the topic for the study further reduced the number of potential participants. The study school operated a parallel class system. Of the two potential teacher participants, one was a colleague with whom I had worked extensively and whom I knew to be supportive of and interested in science education research. This teacher was formally approached, though they had already informally volunteered to participate. The study was explained, detailing what the teacher's involvement would entail.

Thus, the case was selected on the basis of a purposive sampling method (Silverman 2000, Cohen *et al.* 2007). Purposive sampling allows the choice of a case which will illustrate a particular event or process, where the sample is selected on the basis that it will contain the 'characteristics' being sought (Cohen *et al.* 2007). In the case of this study, the characteristics required the use of some representational material during science lessons. Personal knowledge of the teacher and the school enabled me to know that the particular teacher selected did in fact use representations during teaching and that they and the school would be likely to agree to participate because of their interest in and support of education research.

By selecting a single teacher in this school, engaged in teaching a whole series of science lessons, the case study was a naturalistic observation. My position as a former teacher and colleague in the science classroom, knowing the relationship the teacher generally had with children and their response, and the social setting of the science lab where the lessons were held, meant that I knew the 'bounded system' within in which the case was situated (Cresswell 1998). The bounded system within which the case was situated also involved the group of children and the topic they were studying. Thus, a case study approach enabled the portrayal of a teaching situation in reality, in the context of its occurrence (Cohen *et al.* 2007).

The case focused on the topic of the Earth in Space from the National Curriculum for Science in England and Wales (DES 1989). This was chosen by the researcher because this had been the focus of previous pilot studies and was one that the researcher was familiar with. It is also a topic which is currently being investigated internationally. The year group of children for the study was therefore self selected, in that most schools teach the Earth in Space topic in Year 5 (9-10 years).

With the case selected and access agreed, the general questions were revisited to develop specific questions which would be feasible to answer in the context of the case being studied. My knowledge of the school, classroom, teacher and children who were the participants, informed the development of the specific questions.

3.3 The research questions

The general research questions arising from the survey of literature suggested areas of enquiry for the study. The use of a case study method required that these general questions were made specific to the case.

The first general question: *What type of representations do primary science teachers select?* addresses the selection of representations in a general sense. Of the different formats of representational material available, those which were selected by the study teacher to address this particular teaching situation are of significance. Therefore the specific questions became:

a) What types of representation were selected by the teacher for teaching the Earth in Space?

Selection of representations cannot be an ad hoc activity, so therefore there must be some rational behind the teacher's specific selection;

b) What criteria were used for selection?

Once representations have been selected, they are used in lesson. The second general question; *How are these representations used in science lessons?* – relates not only to the types of representation, but to the way they are introduced to the class, the duration of representational use, the way the children are able to interact with the material and how the representational material is actually used once it has been introduced into the lesson. Therefore to make this question specific to the teacher in the study the following specific sub-questions were formulated:

a) How were representations introduced to the class?
b) How much use was made of representations?
c) Were representations used in combination?
d) Were representations used in context?
e) Were the representations 'fit for purpose' with appropriate informational content?
f) Were the same representations used repeatedly?
g) Were the same representations used for different targets?

The selection and use of representational material must be seen as purposeful by teachers or they would not consider using them in their lessons. Therefore, the representational material must be seen by the teacher as making a contribution to learning. The third general question – *Do the representational materials present a cognitively coherent pathway to facilitate the construction of knowledge by the pupils?* – relates to teachers' understanding of how learning takes place. Their views on how learning occurs in the classroom will have consequences for their classroom practice. Using representational material as part of the teaching and learning process suggests that the material selected is considered part of the learning process. Therefore, specific questions relating to the teacher using representations in lessons were devised to address these areas:

a) What was the teacher's understanding of the way learning takes place?

The teacher's understanding of how learning takes place will have consequences not only for their pedagogical practice but also for the organisation and structure of lessons. This will have an impact on how and when representational material is introduced into lessons and also the way it is used. An integral part of teaching primary science is an understanding of the potential misunderstandings children might hold about the phenomenon:

b) Was the teacher aware of any potential misunderstandings the children might hold about the topic?

An awareness of the potential misunderstandings potentially implies a preparedness to address them, in that the teacher might prepare material to counter known misunderstandings. Therefore, the selection of representational material must be part of this process:

> c) Did the use of representations address the commonly held misunderstandings of the topic?

Representational material is unlikely to be used in isolation, in that it may be accompanied by demonstration, explanation or an activity. The creative construction of the representational material becomes significant for all of these activities. Part of the construction of representational material involves aspects of a phenomenon which are included and, as significantly, those aspects which are excluded in the construction. Therefore, the informational content, those aspects of the phenomenon which are included, are of significance if the material is to contribute to the construction of knowledge and the facilitation of learning in the science classroom:

> d) Was the informational content of the representations sufficient for engendering knowledge construction and conceptual change in understanding?

Additionally, the informational content of representational material, the way it is introduced to the class and the way it is used with the class will determine the effectiveness of that material in facilitating the construction of knowledge by the children.

In order to answer these specific questions fully and effectively, appropriate methods needed to be selected for the chosen study situation. The selection of methods with which to pursue any enquiry has a critical impact on the type of data collected. If inappropriate methods are used the data will be inadequate and unable to address effectively the questions posed. The first priority when selecting the methods is to ensure that any methodological decisions made are practicable and suitable for use in a classroom situation and that they will produce sufficient and appropriate data (Morrison 1993).

In designing an investigation to answer the research questions the following points needed to be addressed:

- noting the teacher's use of representations whilst teaching,
- identifying the reasons for the teacher's choice of representational materials and any influences affecting their choice,
- identifying the teacher's notions of teaching and learning,
- identifying the teacher's ideas about the topic being taught,
- monitoring children's learning from the series of lessons.

Noting the teacher's use of representations whilst teaching would involve details of the types of representations used, the frequency of their use and the way they were introduced to the class, the verbal explanation, if any, which accompanied them and any gestures included as explanation or demonstration. Observation of a whole series of lessons would allow all these aspects of representational use to be viewed in the context of the individual lessons and the manner in which they were employed as the topic was developed, therefore giving a context to the use of representations over the whole topic, allowing any development of their use to be accessed both in the context of individual lessons and the whole series.

In addition the teacher's views of teaching and learning, though to an extent discernable from observation of practice in the classroom, needed to be ascertained. This was achieved by discussion in the form of a semi-structured interview to elicit their views.

Though the children were not the focus of the study, it was decided to follow one group of children before and after the series of lesson to see what impact the lessons had had on their learning, by interviewing them. The interview would be semi-structured, to allow their ideas to be expressed but would use prompts to encourage participation.

Therefore, observation of the teacher teaching, discussion with the teacher about their practice and understanding of teaching and learning, generally and about the topic, and pre- and post-interviews with a group of children from the class were considered to be appropriate and effective instruments for the study.

One other important factor influencing both the design of the study and the selection of instruments and methods was my position as the researcher in the study.

3.4 My position as a researcher in a primary science classroom

The impetus for the study arose out of my own teaching experiences with a number of groups of children over a period of years. In addition various pilot studies were undertaken to investigate initial ideas. These are listed in Appendix II.

It was during these pilot studies that I realised the importance of working with children in as natural environment as possible, in order to minimise the potentially intrusive impact of research techniques in a classroom setting. It was, it transpired, also a way I felt comfortable conducting research with groups of children. Initially, studies researching my own practice, and subsequently investigating children's responses to representational materials, were incorporated into our classroom activities as often as possible minimalising the impact of 'being researched' for the children. Naturalistic enquires are usually the domain of ethnographers, and in a way research in the classroom is an ethnographic study of the society of the classroom (Cohen *et al.* 2007). The relationship that develops between the teacher and their class is a very special one and one that I personally believe sets the scene for and is critical to children's learning. It was from this basis of personal teaching experience that I engaged in the research study in Southfield school.

Though at the time of the study I was not employed to teach in the school, the fact that I had recently taught there and had been the study group's class teacher meant that I had a deeper understanding of both the situation in the science lab and of the children and their science teacher. This gave me a unique perspective, an insider perspective, of the study situation.

There are advantages to an insider perspective. The study situation, the science classroom was not novel for me. I knew to, some extent, the way the teacher worked. I understood the relationships between the children, which of them were friends, and how these groups of friends interacted.

The position of the researcher in the research situation has a critical impact on any study. Research conducted in schools and classrooms requires the presence of either instruments or people not normally associated with that setting (Greig and Taylor 1999). By previously investigating my own practice, in my own classroom, I was not only answering questions pertinent to my classroom situation, but also reducing any effect an unknown researcher might have on the study group. The procedures of research practice were supported by a teacher researcher group, enabling the development of my research techniques, skills and knowledge and providing a platform for initial dissemination of findings.

The teachers as researchers movement has been around for over twenty years (Nias and Groundwater-Smith 1988), prompted by the views of Lawrence Stenhouse (1926-1982), who promoted the role of teachers as researchers. He suggested that teachers should not be dependent on the work of academic researchers, but realise the value of their position within the society of the school to conduct their own research into their practices. It is this position, within the school and classroom, which enables a teacher researcher to have a particular insight (McNiff and Whitehead 2005).

Though I was not able to research my own practice for this study, I had access to a number of schools where I was well known by both staff and children. Working in such an environment, where I knew the intricacies of the society of the school, effectively gave me an insider's perspective and enabled me to design data gathering methods to fit around the normal classroom situation, which my position as a former teacher in that situation allowed me to know, to cause minimum intrusion and disruption for both the teacher and children.

3.5 Selecting the methods

As the aim was to record the teacher in as natural, normal teaching situation as possible, I decided to video record the lessons. Observation and field note techniques alone would necessitate reliance on accurate recording, in the form of making notes and sketches, of all aspects of the teacher using representations at the time and in the context they occurred. This was felt to be too great a task given the number of differing activities and materials that would have to be recorded simultaneously. Also, because the researcher was known to the children, the likelihood of being drawn into the lessons was relatively high, further reducing the time available to make notes. This assumption was made on the basis of previous pilot studies in schools where the children were familiar with me as a former teacher and where I was drawn into the lessons by them. Video recording the lessons, in addition to any off camera observation and field notes, made where and when possible, seemed therefore to offer a comprehensive method for gathering the required data. Therefore, the twelve lessons were video-recorded using two machines, one to record the teacher and one to record the children. The machines were synchronised in real time to enable comparison of activities between the two sets of tapes.

Video recording allowed for detailed analysis to be carried out on the material because the material could be repeatedly revisited. Use of individual representations in individual lessons could be related to the rest of the lessons, giving a context to the periods of representation use. Repeated viewing during transcription allowed the teacher's speech and actions to be co-ordinated with the use of representational materials.

In addition to data gathered in the lessons, the semi-structured interview was used to discover the teacher's reasons for the choice of materials and any factors influencing that choice, their views on teaching and learning and what knowledge they thought the topic required for the children. The semi-structured format was adopted to enable the teacher to express their views about the topic and their views about children's learning. Probes, in the form of illustrations from books, were used to elicit the teacher's views about representations in printed material.

The children were interviewed, again using a semi-structured format, before and after the series of lessons. Again probes, illustrations from books, were used as prompts during the interview. In addition, children's exercise books were collected after the series of lessons, so that their notes copied from the board could be viewed.

3.6 Discussion of the methods

The decision to use naturalistic methods of data collection came essentially from my position as a teacher and experience of many teaching situations. Also by keeping the classroom situation as near to normal as possible, the children's responses to the teacher and the events in the lesson would not be substantially altered. Using naturalistic methods, from an insider research perspective, allowed insight into a setting not normally accessible to researchers. The paradigm for the methods was therefore qualitative.

Qualitative research methods, though initially regarded with scepticism, have, over the last twenty years, gained an increasing degree of credibility (Delamont 2002). Their position as 'inexact', non-scientific methods has been largely over ridden by rigorous attention to the factors which may affect their operation. These factors are a part of the reasons that make qualitative research methods flexible and applicable to the varied settings encountered when working with groups of people and particularly in schools.

Quantitative research methods tend to be 'scientific' in that a theory is proposed, an investigation to prove or disprove the theory is designed, the data are analysed using mathematical techniques, and the theory is upheld or reformulated based on the outcome. Experiments used to test theories can be repeated and the theory is reinforced if the repeated experiments produce the same results. This process produces neat, 'clean' data and relies on deductive reasoning for the interpretation of results (Cohen *et al.* 2007). This systematic, objective approach is seen as a search for truths without being influenced by personal bias. Quantitative studies tend to use large numbers of subjects to minimize discrepancies that may arise in analysis. The research tools often used by quantitative researchers in education, questionnaires and surveys, generate data which are specific to that point in time and non-negotiable. Therefore, clarification of answers may be difficult to obtain should the need arise.

Qualitative methods use inductive processes for analysis, allowing variation in settings and participants to be included in the analysis. Qualitative methods are not explicitly 'scientific' nor exactly reproducible but operate on a more subjective basis. Subjects participate in studies and their views are considered as part of the generation of data (Mason 1998). Results from qualitative studies, though not generaliseable to larger populations, nor exactly repeatable, when considered with similar studies with similar subjects and settings may point towards trends. Qualitative methods were chosen for this study to take into account the perspective of the classroom as a dynamic interaction between the teacher and the children during lessons:

> The most fundamental characteristic of qualitative research
> is its express commitment to viewing events, actions, norms,
> values, etc. from the perspective of the people who are being studied.
> Such an approach clearly involves a preparedness to empathise....
> with those being studied, but also entails a capacity to penetrate
> the frames of meaning with which they operate.
>
> Bryman (1988) p61

The methods selected for the collection of data were considered on the basis of their appropriateness for the participants, the accuracy of data collection and the ease with which the data could be collected with minimum disruption to the setting (Burgess 1985, Bryman 1988). Inevitably some compromises were adopted for example, video cameras could not cover the whole of the classroom, as it was rectangular in shape and the fixed furnishings limited the places the cameras could be placed. Placing of the cameras was done in such a way that their impact was minimal. The camera placed at the front of the class was the smaller of the two and positioned as unobtrusively as possible to one side of the class. It was, however, visible and its presence was remarked on occasionally in the initial lessons (Delamont 1992).

3.6.1 Video recording as a method of data collection

The use of video recording as a method for data collection potentially has an effect on the quality and nature of data collected (Delamont 1992, Mason 1998). It cannot be assumed that all study participants are willing to be video recorded (Greig and Taylor 1999). It is therefore important that the research is discussed in detail with all participants. This is particularly the case with a teacher whose practice is being recorded. In this study, once informed consent was agreed, with the teacher, the pupils and their parents, the positioning of the cameras was also discussed with the teacher. This enabled the cameras to be positioned in such a way that they would not interfere with the process of the lessons, be as unobtrusive as possible for both the teacher and the children and yet record as much activity in the classroom as possible.

In this way the teacher was involved in the physical arrangements of the extra equipment in the classroom allowing the presence of the researcher and equipment to be acceptable for both the teacher and the children's requirements in the lessons.

Researchers have a responsibility to their participants and by being flexible and accommodating in the placement of recording equipment I feel I achieved this. Additionally, by including the teacher I did not compromise the relationship already established between us which intrusive data collection methods could have done (Greig and Taylor 1999, Cohen *et al.* 2007). The teacher occasionally made comments 'to the camera' indicating an awareness of its presence. These instances generally took the form of joking asides, which might be interpreted as the teacher being comfortable with being filmed or as a nervous response to being observed. But as Delamont (2002) suggests: "only a researcher with whom the teacher felt relaxed would be told jokes" (p 142) suggesting that the study teacher was comfortable with the situation.

Ideally, the cameras would have been set in place several days before the actual recording was to take place. The circumstances within the school and the commitments of the teacher unfortunately did not allow for this and there was no opportunity to place the video cameras before the series of lessons began they were, therefore, initially novel pieces of equipment. The first lesson, which was moved from the science lab to the children's classroom, gave the children their first opportunity to experience the presence of the cameras. There were some instances of camera awareness (peering into the lens, waving and face pulling) but these quickly subsided as the lesson progressed. Once established in the science classroom, the children only very occasionally indicated their awareness of the cameras. The video recorder which captured the teacher's activities was relatively easily positioned at the back of the laboratory. In this position it was not visible to the children for most of the lesson time.

The video recorder to capture the children's activities was more difficult to place. It was decided to place it on the floor rather than mounted on a table as this allowed it to blend into the background of other apparatus in the room. This resulted in compromising the number of children visible in the recording, approximately one half of the class. This was felt to be a reasonable compromise in return for relative inconspicuity of the camera.

The ethical considerations for filming children in a classroom situation encompass many areas. The head of school requested that they be allowed to negotiate the permissions involved with the children's parents. This was done without recourse to the researcher, other than to establish the focus of the activity. As I had not had the opportunity to discuss the study with either the children or their parents whilst negotiating permissions, I decided to discuss the study with the children in order to be sure that they understood the implications of their participation and also to indicate that they could withdraw at any time. Withdrawal, from a classroom situation, would have been difficult for the children to request, but it was made clear that there were areas of the science classroom which were not covered by the cameras, so that alternative seating could be arranged.

It can only be assumed that the children were happy to participate as no requests to move or withdraw were made. Any child who may have wished to move but felt unable to ask did have the opportunity to move themselves, as seating in the lab was not fixed and could be changed from lesson to lesson, without permission or comment from the teacher. Though there was movement of seating positions from lesson to lesson, the majority of children's positions remained stable and movements appeared to be re-combinations of friendship groups. Given the fact that none of the children who moved appeared to look where the camera was pointing before choosing their place and that children moved in and out of the focal area of the camera, it seems reasonable to assume they were comfortable with being filmed.

The teacher, children and their parents were all offered copies of all audio and video tape recordings and their transcripts, but declined them. All participants were assured that audio and video recordings would remain confidential, to be viewed only by the researcher and selected parts by a supervisor.

The children were used to other adults' presence in classrooms as the school employed a number of ancillary classroom staff, who rotated through classes on a regular basis; therefore, the researcher's presence in the lab was nothing extraordinary and it was inevitable that I would become involved in the lessons, by giving out equipment and helping with the construction of models. The recording of field notes during the lessons became extremely difficult as the children's needs took precedence, so any notes, such as page numbers of books and details of materials used that were too small to be picked up on camera, were written as unobtrusively as possible during teacher introductions, explanations and times when the children were working independently. This was further re-enforcement that the decision to video record the lesson was appropriate to the research.

Video recording the teacher whilst teaching and the children during these lessons was made in order to enable as many aspects as possible of the teacher's interaction with representations to be saved for later analysis. A video recording allows the representation, the speech and the gestures to be viewed in isolation and as part of the whole instance. A pilot study in another school, where the head teacher had refused permission to video record with the children, had highlighted the difficulty of capturing all aspects of the teacher's use of representations using observational techniques and notes.

The fact that lessons were video recorded did not mean that all the activity in the classroom was observed. The children were recorded, to capture their responses to the representational material, in case this was significant. This had the effect of capturing some of the other activity in the classroom. In cases where the teacher's attention was distracted, the cause of the distraction could often be seen, though, as the cameras did not cover the whole of the teaching scene, there were some aspects that were missed by the cameras. If I, as the researcher, had observed the distraction, this was recorded as field notes. In this way the problem of wider contextual data not being recorded due to the limited field of vision of the recording machine was addressed (Morrison 1993, Edwards and Talbot 1994).

Therefore, though video recording for gathering data may initially seem appealing, in that the detailed observation can be delayed to a later date, there are drawbacks to the technique, which were catered for as much as possible by the use of additional field notes and personal observation in the classroom (Mason 1998, Silverman 2000).

3.6.2 Interviews

Observation of the teacher could not supply all the data required to answer the research questions. Additional data were gathered from one extended interview and informal discussions after some of the lessons.

The decision to conduct a semi-structured interview was based on the nature of the enquiry (Creswell 1998, Mason 1998) in that the views of the participants, the children and the teacher, were being sought. The format of semi-structured interviews allows for expression of views by the interviewee, which might not have been included in a structured interview. The same initial 'probe' questions were asked of all interviewees and are given in Appendix III. A semi-structured interview allows both parties (interviewer and interviewee) latitude to pursue a range of topics and shape the content, rather requiring the interviewee to reply to direct questions which may limit replies (Bogdan and Biklen 1992).

Interviewing children differs from interviewing adults (Greig and Taylor 1999). Young children's natural response to adults in a school situation is generally to be compliant and responsive to requests. If children are to take part in a study consensually, their needs must be considered. Though the school had negotiated consent, the nature of the interview was discussed with the children pre-interview and they were given the opportunity to withdraw from the session. Their permission to audio record the interview was also sought. No child withdrew or objected to being recorded. The reasons for this cannot be absolutely determined, nor can it be automatically assumed that compliance indicated total acceptance, as the relationship of the researcher to the children as their former teacher and the context of the school setting, may have influenced their decision. On the other hand, it is that very relationship that might have led to the children's willingness to co-operate.

The children were interested to hear their voices on the tape recording, so the sessions were introduced by allowing each child to say their name. This had a two-fold purpose; it allowed the researcher to check that the equipment was working effectively and, when immediately played back to the children, allowed the children to hear their voices, causing some hilarity and comment, but no withdrawals. It is not possible to assess what effect hearing their voices on the tape may have had on their contributions to the subsequent interview, but none of the children seemed reluctant to contribute. The introductory identification of participants was also useful during the transcription phase, as the researcher had a base identification for individual speakers.

The children were interviewed in a group of four. Personal experience from previous studies (Marsh 1997b, Marsh and Boulter 1997, Marsh *et al.*1999), supported by Greig and Taylor (1999) suggested that groups of children are more generally talkative than individuals, as they stimulate each other with ideas, what Woods (1986) in Delamont (2002, p128), called 'egging each other on'. It also ensures that less confident children do not feel exposed. The size of the group also relates to the contributions individuals will make. Too many, and less vocal, less confident participants will not be heard, too few, and there may not be enough contributions to stimulate discussion. There is less likelihood that the children will talk over each other if they can be sure that they will each have the opportunity to speak. Greig and Taylor (1999) suggest that five or six children per group are the optimal number for an interview so that all speakers have the opportunity to contribute..

Personal experience, from conducting pilot studies, suggests that five children in a group is ideal, with three children being the next best number. Even numbered groups (four, but especially two) seem to have a tendency to agree with each other rather than stimulating debate (Marsh 1997b, Mason 1998). The interview group was chosen by the teacher and comprised four children. Though I would have preferred an odd number, I knew the children in the group and was sure that they would all hold and express their own opinions and that the discussion would be lively. Interview transcription is made simpler if group numbers are limited, giving the transcriber an opportunity to distinguish between individual participants' contributions, an important factor if contributions are to be attributed to individuals. The children speaking their names into the tape aided transcription as the tone of each child's voice could be discerned and related to portions of the tape when conversational exchanges were rapid.

The semi-structured interview format allowed the children to discuss their ideas, in relation to the initial questions posed, and the role of the researcher then became a facilitator of their interaction. Probes, pictures from books, were used to maintain the subject focus. It was important that the children did not feel that the interview situation was an extension of the classroom or that it was their knowledge of the topic which was being tested, but were reassured that their views were valuable and would remain within the confines of the group.

The duration of the interviews was intended to be limited to 15 minutes. Greig and Taylor (1999) and Delamont (2002) suggest this is a suitable time period for young children to be able to sustain interest in an interview situation. However, the pre-teaching interview was considerably longer, approximately 30 minutes, as the study teacher took longer than envisaged to complete work with the other members of the class. The extended period of time did not appear to disturb the group who contributed enthusiastically for the whole period of time.

In the case of the teacher interview, the relationship between the researcher and the teacher was such that the interview took the form of an informal discussion between two friends or well acquainted colleagues. The interview, which took place on completion of the series of lessons, meant that the teacher and researcher had been working together for the whole study period (12 lessons). In addition, we had numerous previous shared teaching experiences and had been together on residential fieldtrips. Due to a lack of an available room the interview took place in an unused stairwell facing the playground, causing the children great amusement, and providing a relaxed and informal context.

Though direct questions, in the form of a structured interview or questionnaire, would have produced answers in all the interviews, there would have less opportunity for discussion and clarification of the ideas put forward by the participants. The intention of the interview with the children was to seek their understandings of the topic, with specific reference to the reasons for seasons and the moon phases. In the event, the interviews mainly dealt with the reasons for seasons and the construction of the pages of the books.

Kvale (1996) proposes that a semi-structured interview is; "a conversation that has structure and a purpose" (p6) and its intent is to obtain that person's description of the world in which they operate. He also suggests that a research interview cannot be a conversation of equals because the interviewer has knowledge of the situation that they want to investigate and in that way they have control over the process. Whilst this is to an extent true, the study teacher had discussed the research topic with the researcher prior to the commencement of and during the study and could be assumed to have a reasonable knowledge of the issues to be discussed in the interview. So, whilst the topic under discussion was instigated by the researcher, the study teacher was free to take the discussion in any direction they felt appropriate. As both the researcher and the study teacher had a mutual interest in the teaching of science and a shared interest in the types of representations that might be used to illustrate scientific phenomena (we had previously ordered materials together), the interview was as near to a discussion between equals as any discussion between colleagues might be. Inevitably the researcher had some effect on the direction of the conversation, having a deep interest in the study topic, not necessarily shared completely by the study teacher. Although leading questions were avoided at a conscious level, unconscious clues may have influenced the teacher. This is not feasible to assess, as the interview was only audio recorded, so any unconscious gestural pointers from the researcher are unrecorded.

Probes were thought to be an appropriate tool to use in the interviews in case there were any difficulties in enabling the children to express their ideas. Although it was felt that the interview situations were as informal as possible, there was the possibility that some of the children would find it difficult to formulate their ideas. The probes also served to keep attention focused on the intent of the interview. There is a possibility that production of the probes affected the expression of the children's ideas, in that, if the children had not yet contributed an idea and were then confronted with representations which did not accord with their ideas, the probes may have had the effect of changing their potential contribution. This is almost impossible to ascertain.

3.6.2.1 The interview probes

The interview probes were three pictures from children's factual books and textbooks, showing representations of the seasons. The initial inquiry for this study had focussed on this aspect of the Earth in Space topic. The probes had been selected from pilot studies using a series of nine pictures which were discussed with groups of children in three different schools. These nine examples were chosen by the researcher, based on the criteria:

- they were illustrations that previous classes had enjoyed
- scientific accuracy
- general appeal in terms of colour, layout and textual content.

The pilot studies were undertaken to establish which type of illustrations would be suitable to use with children. It was felt that selection solely by the researcher might place an unwanted bias on the type of illustrations used as probes, resulting in the children not engaging sufficiently with any probes to be used during interviews. This in fact was the case, as illustrations regarded by the researcher as being good examples of the phenomena were rejected by the children for several reasons but mainly because they were regarded as too complicated and therefore inappropriate for their age group.

The children participating in the pilot studies were grouped on the basis of who was available and willing to contribute during their playtimes. In these groups the children discussed the illustrations with a view to deciding which they all agreed would be the best ones to use for a lesson or personal project work. Interestingly, the groups in the three pilot study schools all chose the same illustrations from a selection of nine. The results from all the groups were combined and the three most popular illustrations were designated interview probes for the study.

Therefore the three interview probe pictures were selected on the basis of being the best representations of the seasons, in the opinion of the children, was based on their understanding of seasonal change and the appeal of the illustrations. This was not necessarily accurate, but the probes were to be used to stimulate discussion, so it was felt that illustrations chosen by children as being 'good' representations would make appealing probes for other groups of children. The same prompts were used in all the interviews (Figures 3.1, 3.2 and 3.3), in addition a concept cartoon (Keogh and Naylor 1999) about the seasons was included and is shown in Figure 3.4. This was included as it represents the reasons for seasonal change in a way which promotes discussion, rather than as an illustration of factual aspects, as was the case with the other prompts. It was not introduced until later in the interview.

The decision to use three illustrations for the pupils to discuss was based on the work of George Kelly in his theory of personal constructs, where he proposed three elements for choice so that a comparison was possible. A choice of two usually results in a direct choice of one or the other, whereas a choice of three forces comparisons of aspects (constructs) to made (Denicolo and Pope 2001). Though the children were not being asked to make a choice, using three illustrations resulted in discussion being generated about the relative aspects of the illustrations. In this way it was hoped that the discussion could be opened up to accommodate all their ideas.

[redacted]

Image redacted due to third party rights or other legal issues

Figure 3.1 Interview probe 1 – Eureka 2R (Chapman *et al.* 2001) pages 40-41

OUR EARTH AND THE SOLAR SYSTEM

The four seasons

Places on the Earth that are not near the equator have four **seasons**. Because the Earth is tilted one pole or the other is pointed towards the Sun as it moves in its orbit. When the North pole is pointing towards the Sun it is summer north of the equator and people living in the south have winter.

What causes the four seasons?

Our Earth makes one complete orbit around the Sun every year. The tilt of the Earth's axis causes the seasons because in summer we have more hours of sunlight and in winter the nights are longer. So in summer there is more time for everything to get warmer.

Image redacted due to third party rights or other legal issues

What happens at the winter and summer solstices?

In Britain the shortest day happens on or about December 21st. This is called the **winter solstice**.

On this day the Sun is directly over the tropic of Capricorn and the North pole points away from the Sun. In Britain the Sun is low in the sky and gives little sunlight.

Image redacted due to third party rights or other legal issues

Image redacted due to third party rights or other legal issues

On or about June 21st the Earth has moved half way around its orbit. This is the day when we have the most hours of daylight and is the **summer solstice** or midsummer.

On this day the Sun is directly over the tropic of Cancer and the North pole points towards the Sun. In Britain the Sun is high in the sky and we get a lot of sunlight.

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Figure 3.2 Interview probe 2 – Letts Educational (Jarvis 1998) p118

Image redacted due to third party rights or other legal issues

[redacted]

Figure 3.3 Interview probe 3 – Usborne (Tahta 1990) p 8

Image redacted due to third party rights or other legal issues

[redacted]

Figure 3.4 Concept Cartoon Keogh and Naylor (1999)

3.7 The data

The data collected during the series of 12 lessons comprised:

- Video and audio recordings of all the lessons as itemised below in Table 3.1
- Field notes made during and after lessons (seating arrangements, occurrences out of view of the camera, teacher comments)
- Copies of the text books and teacher's notes from the scheme used by the teacher
- Copies of the worksheets used by the teacher
- The National Curriculum programme of study for the Earth in Space topic and QCA 5e
- Audio recording of the interview with the teacher
- Audio recordings of the pre- and post- interview with a group of children
- Copies of children's exercise books
- Examples of models constructed by the children
- Copy of the poster used by the teacher
- Information about the objects used as representational material (dimensions of spheres, distances measured).

The video recordings were transcribed verbatim using a system of codes to denote the different activities. Note was made of the various types of activities that occurred during the lessons. All the speech and gesture used by the teacher whilst using representation were highlighted. This enabled the teacher's speech to be matched to their use of representations throughout each lesson.

The recorded audio interviews were transcribed verbatim. Notes were made about the various references to the science topic and representations in the case of the children and to teaching, learning, representations and subject knowledge in the case of the teacher.

Therefore, for the series of lessons, there were data about the representations, how they were used generally and specifically and what type they were. There were also data about the teacher's ideas about representations. This corresponds to the data identified for collection in the methodology.

Lesson	Tape no.	Subject	Tape no.
1	1A teacher	The Solar System	1B children
2	2A teacher	Order of the planets	2B children
3	3A teacher	Distances between planets	3B children
4	4A teacher	Sizes of the planets	4B children
5	5A teacher	Computer research	5B children
6	6A teacher	Computer research	6B children
7	7A teacher	Relative sizes of Earth, Sun and Moon	7B children
8	8A teacher	Day and night	8B children
9	9A teacher	Seasons	9B children
10	10A teacher	Graphs	10B children
11	11A teacher	Graphs and some phases of the Moon	11B children
12	12A teacher	Phases of the Moon	12B children

Table 3.1 Fieldwork videos.

The data were subjected to triangulation, in that the video recordings collected data on the teacher's use of representations and their pedagogical practice in reality and the interview with the teacher recorded data about views on representations and teaching and learning. Triangulation in qualitative research is important because it allows insight into the situation from more than one viewpoint (Cohen *et al.* 2007). If analysis of the data is to be inductive, then collecting data about the same event from more than one source enables a fuller explanation to be generated (Greig and Taylor 1999, Silverman 2000).

The teacher's knowledge of the topic was to some extent apparent in the video recordings of the lessons. Explanations of the various systems, such as day and night and the seasons, require relatively detailed subject knowledge. But this would have been tempered by the knowledge that it was felt that the children should be given. Direct comparison between the views expressed in the interview and those from the lesson therefore had to be drawn with caution.

Kvale (1996) urges that care should be taken when interpreting interview material, so that the actual meanings of the interviewee are distilled. The interviews, both those with the children and the teacher, were transcribed as accurately as possible and as soon after the event as possible. In this way any asides or contributions that were not audible on the tape could nearly always be recalled from memory. Words and sentences that were stressed were marked, as this indicates the speaker felt that their contributions on these points were particularly important. Though audio recording is easier than making notes during an interview, in that the whole dialogue is obtained, sense can be lost if attention is not paid to the fluctuations of stresses and pauses, which are of importance and give meaning to the interviewee's contribution. This was taken into account when the transcripts were searched for references to aspects of the topic, in the case of both the teacher and the children and for references to teaching and learning, choice of representations and personal understanding of the topic by the teacher.

The transcripts were not subjected to analysis by computer programme as it was thought to be more effective to read and re-read them, looking for pertinent material. This was considered a valid method because of the manner in which the interviews were conducted. Though great care was taken to ensure that personal knowledge of both the teacher and the children did not affect the interpretation of individual contributions, it is always possible that there was some effect at a subconscious level. This may only be relevant where the contributions were vague or indistinct, but might also have affected general transcription. Transcribing the interviews as soon as possible after they took place contributed to negating this effect, as nuances and contextual inferences were still memorable in the main, allowing for inclusion or clarification of indistinct or non-verbal additions.

The methods outlined above were used to gather the data from the lesson and study participants. The actual analyses of the lessons, use of representations and interviews reported in the next chapter were carried out on completion of the video recording, though each video was briefly checked the same day in an effort to identify any areas that immediately appeared to need clarification. The attempt was made to collect as much data as possible in the time the researcher spent in the school. This was a personal decision based on the fact that the study teacher had been generous enough to allow lessons to be recorded and to submit to an interview and further or continuous requests for clarification of points missed at the time were felt to be too intrusive.

The way in which analysis of the video recordings and interviews was undertaken, and the methods used to analyse the representations used by the teacher are described in detail in the following chapter.

Chapter 4

Analysing the data

4.1 Introduction

The focus of the study was a teacher using representations in primary science lessons and the questions posed enquired into the material selected and the way they were used by the teacher. The data collected were designed to answer the questions in a specific classroom and relate to one teacher. The design of the study allowed a variety of data to be collected as set out in Table 4.1.

The data were collected from different sources to allow for triangulation (Cohen and Manion 1994, Silverman 2000) and the methods of analysis selected had to account for these different sources of data. The data relating to representational material did not stand on their own, and the context of the appearance and method of use of the material in the lessons needed to be determined. The teacher's views on representative material also related to its use in the lessons. For this reason several layers of analysis were needed to efficiently and effectively extract the pertinent details without losing the overall context of the lessons.

The representational material itself was a key element in the study both as it was used in the teaching context of the lessons and because of the informational content the teacher aimed to make available for the children's learning. A system of analysis to determine the informational content of the representation both on its own and within the context of the teaching situation was therefore selected.

The systems of analysis used for all the data are discussed as they relate to the different sources of data and the two analysis grids used to determine the informational content of the representational material are described in detail with examples of how they were applied. One grid, Goldsmith (1984) relates the lines, blobs and edges present in an image to the potential interpretations and the relevance of accompanying text. The other grid enables determination of scientific information in terms of structure, behaviour and mechanism of phenomena present in any mode of representation.

Data	**Number**		
		Individual Duration	Total Duration
Video recordings	24 (2 per lesson)	1 hour (approx)	24 hours (approx)
Audio recordings	3	Teacher – 45 minutes Children 1 – 30 minutes Children 2 – 15 minutes	90 minutes
		Details	
Teaching materials	1 1	Copies of worksheets Copies of teachers notes for the Spectrum scheme	
Wall poster	1	Photographed	
Exercise books	2	Completed notes from lessons	
Text books	2	Spectrum 7 Coordinated Publishers KS2 Science	
End-of-topic posters	3	Copies made	
Models made in the classroom	2	Copies made of string model for planet distances Fan model for planet sizes (example retained)	
Field notes	Contained details of off camera activities, seating arrangements, dimensions of whiteboard, copies of board writing and diagrams, details of materials used in lessons, discussions with the teacher after lessons, observations of other activities in the school affecting the teaching situation.		

Table 4.1 Details of data collected.

Representational materials are a key element of this study as they occur in the context of the lessons and the manner in which the teacher utilises them and the implied informational content of this use. Whilst accepting that knowledge can be constructed from any instance of interaction with representational material, this study intends to take a step further by looking at the way the images are constructed to determine what aspects are illustrated and therefore made accessible for facilitating knowledge construction. This involves the lines and colours used in the creation of the material in the first instance, but also includes factors added by the teacher as explanations and gestures. The two analysis grids are intended to determine these factors.

The Goldsmith (1984) grid was selected for use on the basis that it supports theories of visual perception and also takes into account the findings of studies about diagram and illustration construction (Hartley 1994, Mayer and Gallini 1990, Tversky *et al.* 2000) outlined in Chapter 2. Knowledge construction from interaction with representational material is dependent on the initial understandings held; therefore the Buckley and Boulter (2000) grid takes into account those aspects of a phenomenon which form the basis for complete understanding.

4.2 The recorded data

The first level of analysis for all the recorded data was checking the material on the day of recording. The second level was verbatim transcription. This gave a record of the speech in the lesson and the contributions of the teacher and children in their interviews. Initial transcription attends only to the words used by a participant leaving the possibility of loss of contextual details. A verbatim record of the words spoken provides a basis for further analysis (Delamont 2002). Systems of coding contributions by participants can reinstate some of the contextual details lost in verbatim transcription. Therefore any verbatim transcriptions require further layers of analysis to be applied to capture the contextual inferences from the setting. The layers of analysis applied to all the recorded material are explained for each instrument in turn.

The tapes and transcripts were checked for accuracy of transcription by two independent others, who were not teachers, who did not know about the study in detail and who did not know the study teacher, the children or the school. The few differences that were found were checked again by me against my original transcriptions. Having the video tapes and interviews transcribed additionally by independent others allowed me to regard them as an accurate account of the verbal content of the recordings.

4.2.1 Video recordings

The initial phase of analysis, viewing of recorded material took place after each lesson, in the first instance to ensure that the machines had worked, and then to see if there were any instances which needed clarification for any reason. These were checked against field notes and if further clarification was needed this could be attended to in the next observed lesson. There was a total of 24 hours of video recorded material of the 12 lessons from the two cameras used. The video recorded material was filmed from two separate sources each with an integral microphone. This allowed any indistinct areas of speech on one tape to be checked against the other. In fact there were very few indistinct instances of the teacher talking to the class.

The third level of analysis was to draft onto the speech, the gestural movements made by the teacher. Initially this was done for all of the teacher video recorded material, to discover which gestural movements were directly related to teaching using the representational material. As described in Chapter 2, gesture plays an important role in classroom communications and the aim was to note movements made when using representational material. As gestural movements were to form part of the material for analysis of the informational content of representational material it was important that the movements made could be seen as deliberate and relating to the representation. Other gestures, not associated with representational material, would still serve as communicators to the children, but these were not regarded other than characteristics of the teacher's style of teaching.

The various studies of gesture described in Chapter 2 (Neill 1991, McNeill 1992, Crowder 1996, Goldin-Meadow 2004) were used to define which gestures could be regarded as conscious and unconscious. Some unconscious gestures, such as hair and face touching, are relatively easy to read in the context of the teaching situation, but for expansive hand and arm gestures, which could be used to imply velocity, movement or shape, it was critical to identify them as conscious or unconscious and related to the representational material because of the effect they would have on its use with the children. An example transcription combining speech and gesture with representational use is given in Appendix IV. This example was chosen because of the amount of gesturing which occurred and shows how each incident of gesture was individually noted. Incidents of gesture related to representational use could therefore be clearly seen.

The fourth level of analysis was to note the types of activities which occurred in the classroom during the teaching sessions. This was so that periods of representational use could be identified and isolated. Therefore the material was repeatedly viewed to identify categories of activities. The categories were chosen on an interpretive basis in that they were identified from periods of activity which appeared to be repeated in most lessons and in terms of my own experience and understanding, as a teacher, of the activities that were observed and taking into account those activities identified by others as relating to a teacher's style of teaching (Galton and Simon 1980, Joyce *et al* 1992, Sizmur and Ashby 1997).

Data, such as the video recording of the lessons, require several layers of analysis due to the nature of the material (Cohen *et al.* 2007), and can be treated in either a quantitative or qualitative manner. Though counts were made of the occurrence of categories throughout the series of lessons, these were not used in a quantitative manner other than to identify the proportion of general activities, and representational use in particular, occurring in the lessons.

Observational material in any setting is, on analysis, open to subjective interpretation (Creswell 1998). Performing repeated layers of analysis can go some way to take account for this. My status as an insider, participant researcher had a particular impact on the gathering of data, as discussed in the previous chapter. For the purposes of analysis, therefore, clear structures were put in place to ensure rigor. These were objectively viewing the activities in the classroom using categories I had identified and which were also acknowledge as classroom activities by others and ensuring that any off-camera activities were noted in field notes (Alexander *et al.* 1992, Joyce *et al.* 1992, Sizmur and Ashby 1997). On the other hand, my position as an insider allowed me to note classroom activities and understand their context, but I was likely to have expectations of the types of activities likely to occur in a classroom. Thus the categories arose to an extent from my own experience in the classroom, but had also been identified by others'. The classroom is a dynamic context; therefore identifying activities is not a simple matter of counting instances. Each moment of the video recorded material contained some form of action and my own experience as a teacher contributed to the interpretation of each of these moments and the subsequent categorisation. However, by taking account of the identification of categories by others it gave their allocation integrity and validity.

Once the activities in the lessons had been placed into categories, the instances of representational use could then be isolated for further analysis. The categorisation of representational use was, however, to some extent pre-ordinate, as representational use was a key issue in the observation data. Therefore the categories for activities in the classroom were:

- Settling down – the arrival of the children. This was the period where the children came from different lessons to the science lab and chose their seats
- Introduction – the teacher calling the class to order and recapping on the previous lesson and telling them about the current lesson and proposed activities
- Questioning – periods of question and answer – not related to representational use
- Explanations – where the teacher described a procedure for the children to follow – not related to representational use
- Representations – where materials were used to illustrate points in the lesson
- Giving out books and equipment
- Children working on their own – having been set a task
- Writing on the board – for the children to copy into their books – not related to representational use
- Recapping – an overview of the material covered in the lesson, and reiteration of points already covered
- Closure – instructions for dealing with exercise books and lab stools.

A count was made of the categories of activities for each lesson and for the whole series of lessons to give a view of the organisation of the lessons on both an individual and an overall basis. This would give an indication of the teacher's pedagogical practice, which could be compared with the views expressed in the interview. It also gave the amount of time representations were used in individual lesson and over the whole period of lessons. These periods of representational use, once isolated from the other activities in the lessons, were subjected to further analysis using the analysis grids described in section 4.3.1.2.

4.2.2 The audio recordings

The audio taped data consisted of an interview with the teacher and two interviews with children. Again, all the tapes were transcribed verbatim and any relevant observations from field notes jotted onto the transcriptions. The tapes were also transcribed by two independent others and the transcriptions checked against my own for accuracy and contiguity.

Audio tape transcriptions differ from video tape transcriptions because there are no visual cues to the speaker's contribution. This immediately removes a layer of context from the transcribed material. By transcribing as soon as possible after the event, some of the context may be recalled, but this is subjective recall and unless the transcription is validated by the participant has to remain subjective. Copies of the transcriptions were offered to the teacher and the children but they declined the opportunity to verify the contents. As it is not ethical to insist that participants read transcriptions of the material they recorded, the transcriptions have to stand with this subjective element.

The content of the audio material can be given meaning other than the literal meaning of the words by systematically coding verbal contributions. Deciding which aspects of contributions to code for is dependent on the use that will be made of the recorded material. Interviews generally seek to elicit ideas, perceptions and views. Anything expressed by the participant can only be viewed as their ideas at that time. Many factors could influence the views expressed. The relationship of the interviewee and interviewer is one critical factor. In the case of the children, they knew the researcher as a teacher and this is likely to have influenced their contributions (Greig and Taylor 1999). As the teacher was a friend and colleague, this too would have had an influence on the views expressed (Cohen and Manion 1994, Mason 1998). However, the views expressed in the interviews are the material with which the researcher has to work and as such must be regarded as valid for that time. I would like to think that the relationships I had with both the teacher and the children contributed positively to the interview situation, but there is no rigorous method of validating this assumption.

Coding interview contributions can be achieved in a number of ways depending on the use to be made of the material in the interview. There are a number of disciplines which examine texts and speech in detail. One such discipline is conversation analysis, where texts are coded for analysis to explore the organisation of ordinary talk, allowing a view of the organisation and content of the speech which enables individuals to construct meaning in a social context, in effect the different ways people talk to each other (Silverman 2000, Cohen *et al.* 2007). It is a systematic system which facilitates replication, making it a powerful tool for analysis. Though conversation analysis is an established method of analysis for examining the content and organisation of speech, it was not used for this study as only intonation and emphasis, rather than detailed organisation of the teacher's speech, was required.

4.2.2.1 The interview analyses

The verbatim transcriptions of the teacher and the children were treated differently. The intention of the teacher interview was to seek ideas about teaching and learning and representational material. The verbatim transcription of the teacher interview was therefore coded. The words used, and relative emphasise placed on the words, were felt to contribute to the importance the teacher placed on the views expressed. Therefore a system of coding which accounted for descriptive vocabulary, intonation and emphasis was devised using symbols from discourse and conversation analyses but most commonly found in Jefferson Transcription Notation (Atkinson and Heritage 1984). The actual coding system used is given in Appendix V and an example transcription is provided in Appendix VI. This particular excerpt was selected to show how the coding was used to establish emphasis in the transcription.

4.2.2.2 The teacher interview

The semi-structured nature of the teacher interview meant that the teacher had the opportunity to disclose their views about a number of areas. Prompts, illustrations from books, were used to elicit ideas about representational material. The transcript was searched for significant incidences. These incidences were references to:

- teaching
- learning
- personal knowledge of the topic
- misconceptions
- representational material.

These were the five categories to which the teacher's contributions were assigned. Each contribution in each category was then coded to identify descriptive vocabulary and emphasis, highlighting areas and aspects of those areas the teacher felt strongly about. The statements made by the teacher in each of these categories, coded for stress and emphasis, could then be interpreted to determine the strength of the view expressed. This would give an indication of the amount of significance the teacher attached to the view. The interview with the teacher was relatively straightforward to transcribe as there were just the two voices on the tape. The voices were sufficiently different for a distinction to be made between the speakers.

There were occasionally times when there were asides made during the discussion, which were relatively indistinct on the audio recording due to the volume at which they were uttered. As the material was listened to immediately after the interview (within 2 hours), the transcription of these few indistinct moments was supplemented by recall of the instance. It is reasonable to assume that the recall of these instances was relatively accurate due to the immediacy of the transcription. There has, however, to be some scope for an element of doubt as the recall was mine alone and therefore subject not only to my memory of the instance but also my interpretation of the instance, both at the time and as recall. This is one of the drawbacks to using transcribed material as a data source, as the researcher is inextricably bound into the research situation and therefore cannot be absolutely objective (Mason 1998, Silverman 2000). As noted earlier the transcript was offered to the teacher for checking, but this was declined. The categories identified in the interview as relating to the topic of the lessons were regarded as being influential in representational use and were therefore subjected to a further level of analysis.

The issues of subject knowledge and the knowledge the teacher felt the children should have, were analysed using the Buckley and Boulter (2000) grid system to identify references to the structure, behaviour and mechanisms of the scientific aspects of the phenomenon. All these aspects of any phenomenon are important for constructing knowledge from the representation. If only one or two aspects, structure and/or behaviour are present, then the mechanisms and behaviours of the structures within the phenomenon may not be not explicit, leading to the potential for misunderstanding of the complete phenomenon.

4.2.2.3 Coding the interview

The decision to devise a novel system of coding the interview was taken because of the use that was to be made of the resulting data. It was not intended to subject the data to statistical analysis, nor compare the interview with other interviews. Therefore using an abbreviated coding system adapted from content and conversation analysis allowed particular aspects of the teacher's verbal contributions to be highlighted and given contextual relevance. Other coding systems tend to delve more deeply into the construction and intention and exchange of speech or text.

Content analysis procedures aim to examine systematically the contents of written data. It is a research technique which makes "replicable and valid inferences from texts" (Cohen *et al.* 2007 p475) and the texts referred to are often documents in the public domain. Text, however, can be viewed as any written material, so content analysis can be applied to transcribed material. But as content analysis focuses on linguistic features of language, as units of analysis, it is a deductive process generally leading to statistical analysis of the text. Whilst it might be interesting to analyse the teacher's use of words in a statistical manner, the result would not be useful for answering the research questions posed by this study, so only the coding systems for words were adopted.

Coding the interview in this way enabled aspects which were strongly expressed to be identified. Identifying strongly expressed views would highlight those areas the teacher felt were important. This would allow an insight into the teacher's pedagogical practices, their views on teaching materials and the topic itself.

4.2.2.4 The interviews with children

The pre- and post-teaching interviews with the group of children were transcribed verbatim. The intention of the interviews was to compare their discussion about the reasons for seasonal change pre- and post-teaching. One issue had been selected because of the limited time the children had available for interview. The initial interview though scheduled for fifteen minutes was actually longer. Though the children's contribution was not part of the focus of the study, the interviews gave some measure of their understanding of the reasons for seasonal change before and after the teaching session.

The interviews were searched for all references to the reasons for seasonal change. These references were counted in order that the pre- and post-teaching references could be compared. These interviews were not coded in the same way as the teacher interview as the issue was actual references to reasons for seasonal change. It was considered that any contextual details would not add to the quality of the children's contributions; therefore the coding for descriptive detail, as in the teacher interview, was unnecessary. An example transcript is in Appendix VII showing how the various categories were marked using colours to denote the differences.

The references made to aspects of seasonal change were categorised. The categories were designated according to the feature of seasonal change they expressed. The categories were pre-determined, arising from the literature concerning misconceptions about seasonal change described in Chapter 2:

- Physically observable changes – e.g. daffodils in spring (structure)
- Naming of seasons (structure)
- Changes in weather – e.g. rain in winter (structure)
- Knowledge of differential temperatures – e.g. cold in winter (structure)
- Knowledge of differential light intensity – e.g. darker in winter(structure)
- Reasons for differential light intensity – e.g. the angle of incidence of the Sun's rays (behaviour/mechanism)
- Reasons for differential temperature – e.g. the angle of incidence of the Sun's rays (behaviour/mechanism).

A count was made of the categories referred to by the children in both interviews and the two counts compared. The categories divide into sub-categories, those of structural references and those referring to the behaviours and mechanisms as devised by Buckley and Boulter (2000) involved in seasonal change only as the second interview children's only briefly covered the phases of the Moon. The behaviour and mechanism aspects have been combined in the above list because the categories of potential misunderstandings identified from previous research do not differentiate between aspects of behaviours and mechanisms. The above categories describe the types of misunderstanding likely to be expressed by children and follow the progression of understanding of the reasons for seasonal change as identified by previous research (Mali and Howe 1979, Sadler 1987, Baxter 1989).

4.3 Selecting the periods of representational use

These incidents of representational use were then individually revisited and the teacher's speech and gestural movements during use noted to correlate with the representational material. In the case of the incidents where gesture and explanation were used as the representation themselves, these were treated in the same way as a physical representation, where speech accompanying the gesture was counted as part of the representation.

There are problems with isolating incidents in this way. There is a risk that the data may be decontextualised resulting in their position in the sequence of events being lost or misrepresented (Silverman 2000, Cohen *et al.* 2007). Though the context of the use of representations is important, for this level of analysis of the representations themselves, removal of the incidents from the rest of the data was felt to be valid at this point so that they could be analysed separately. The context of the use of representations forms another layer of analysis.

The transcriptions of the periods of representational use were again revisited, this time to code the teacher's speech. The code used was a combination of markings and conventions from other systems. The teacher's speech was not to be regarded in isolation, but rather as an adjunct to the use of representations. The words used, and the relative emphasise placed on words were felt to contribute to the presentation of the representational material. Therefore a code which accounted for descriptive vocabulary, intonation and emphasis was devised using symbols from content and conversation analyses. The actual system used is given in the Appendix V along with an example from the transcription of a lesson.

The periods of representational use isolated for analysis are detailed in Table 4.2. The type of representations used and the topic they were being used to illustrate are noted.

Topics such as the Earth in Space requiring the illustration of aspects not accessible in an ordinary classroom may make use of one or more of the different modes of presentation. In the case of the contents of the Solar System, this might be orreries, wall posters, computer programmes or video simulations of the Sun and planets within the system. Therefore, the purpose of representations used in this way is to convey factual information about the phenomenon being studied. As is it extremely difficult to include all aspects of the features of the Sun and planets in one representation of the Solar System due to the relative sizes and distances involved, the informational content of any representation is likely to be flawed.

These shortcomings in informational content can be compensated for with explanations by the teacher. Explanations can comprise speech and gesture. If the informational content of a representation could be determined and the additions by the teacher also determined, then an overall picture of the material the children are presented with, from which they can construct their own knowledge, can also be determined.

Lesson	Type of representation used	Topic
1	Board	Contents of the Solar System
2	Board Worksheet Large images of Sun and planets	Order of planets
3	String model	Relative distances between the Sun and planets
4	Fan model Poster	Relative sizes of the planets Physical features of planets
7	8 different sized spheres Beach ball & globe	Relative sizes of Earth, Sun and Moon
8	Board Book Globe	Day and night
9	Beach ball Globe Board Small bead	Seasons
12	Worksheet Board	Phases of the Moon

Table 4.2 Episodes of representational use per lesson.

The focus of the study, a teacher using representations in a primary science classroom during teaching of the Earth in Space, not only required noting representational use, but also other activities in the classroom as part of the context of representational use. The representations are a key element both as they occur within the classroom teaching context and because of their informational content that the teacher aims to make available for learning. If representational material is to contribute to the construction of knowledge within the science classroom, the material selected has to be appropriate in terms of its informational content and physical construction. It has also to be contextually relevant to both the teaching situation at that time and the cognitive development of the children who are accessing the material. Methods of assessing these factors require an analysis system that will take into account the construction of the concrete model or image and any accompanying text. Text can be viewed as the teacher's speech whilst using representations and any gestures used can be viewed as part of the representation.

All representations were subjected to an initial analysis to determine the levels of informational content present as they were used in the classroom. The individual representations were re-analysed using this combination of grid systems, with the teacher's speech and gestural movements added in. The analysis and coding system devised by Kress and van Leeuwen (1996) presents a view of the way in which meaning can be constructed from images. It has its basis in social semiotics and socio-cultural influences. Whilst these aspects are critical influences on any viewing instances, the analysis systems used for this study focus on the intended scientific principles presented in images and models and how differences in depiction can alter the meaning that can be constructed from these images and models. The Kress and van Leeuwen (1996) system focuses on design for successful communication rather than any decisions about specific content (Gates 2004). So whilst the system of analysis proposed by Kress and van Leeuwen (1996) was considered, it was not felt to address all the areas of interpretation of representations in a way that would highlight the scientific principles and their presentation in representational materials, nor was it judged to address adequately aspects of construction in terms of interpretation using the principles of visual perception theories.

Thus, details of each episode of representational use could be identified and the informational content of the representation itself and with teacher additions could be assessed. These results were not subjected to statistical analysis as they resulted from a systematic interpretation of the individual episodes.

4.3.1 Description of the analysis grids

The topic of the Earth in Space in the National Curriculum for Science being taught inevitability requires the use of physical models and images for demonstrations and explanations of the structures, behaviours and mechanisms of and between the principles objects – the Earth, Sun, Moon and planets – involved, because of their inaccessibility in reality. Therefore, the informational content of representations becomes relevant to teaching and learning about the Earth in Space topic in that representational material has a role in facilitating and promoting the construction of knowledge and the formation of or restructuring of individual mental models.

Representational material used in the science classroom may be presented in a number of formats or modes. Any system intended for use in the analysis of a range of representational modes needs to be able to address all aspects of any representational format presented. The Kress and van Leeuwen (1996) analysis and coding system presents a view of the way in which meaning can be constructed from images based on social semiotics and socio-cultural influences. Whilst these aspects are critical influences on any viewing instance, the analysis systems used for this study focus on the intended scientific principles presented in images and representations and on how differences in depiction can alter the meaning that can be constructed and also provide scope for application to a breadth of different representational situations.

Many existing analysis systems have been developed to analyse a single format of representational material (Prosser 2001, Unsworth 2001). Whilst these are useful alternative ways for looking at individual types of representational material, it was considered, from experience, that it was unlikely that a single mode of representation would be used in a primary science classroom and therefore a system which could be used with many modes of representation was needed.

Having worked in the school and taught this topic I had a general idea about the types of representation that were likely to be used, and that they were likely to be presented in a range of modes, so the analysis systems used for the study needed to have sufficient scope to cover all modes. In the event, the study teacher had selected a newly published scheme of work for the basis of the lessons, so though the representations did indeed embrace a number of modes, they were not ones I had used previously or had personal experience of. Therefore analysis of the representational material was freed from personal bias from previous encounters with the representational material, ensuring a greater degree of objectivity

The combination of the systems meant that they could be used with textual representations, physical models and teacher explanations using objects and diagrams, therefore covering a range of representational modes.

The analysis system developed by Goldsmith (1984) is used to determine the levels of informational content of the combination of text and images. The system developed by Buckley and Boulter (2000) enables the presence of processes involved in the operation of a phenomenon to be determined.

Goldsmith came from a linguistics background and turned her attention to illustrations and their accompanying texts when she observed her granddaughter relying on pictures to interpret the accompanying text. The aim, to develop a system of analysis to allow evaluation, in terms of the accessibility of information, of the combination of text and image, is underpinned by this linguistic and semiotic background. In addition, this method of analysis takes into account the Gestalt and visual perception notions of lines, blobs and form recognition interpretation of visual images.

A twelve-category system was developed by Goldsmith to focus on this idea. These categories were derived from numerous studies previously undertaken in the field of illustration, linguistics and semiotics and adapted by Goldsmith (1984) to formulate a system for analysis in a grid formation.

The grid consists of semiotic levels of information identified as being present in visual images, levels of interpretation and the accompanying text. Goldsmith (1984) proposed three semiotic levels available in any illustration, the syntactic, semantic and pragmatic, when viewed.

The syntactic level does not assume the viewer recognises or identifies the image in the illustration. It is the simple process of recognition of separate lines as being distinct from the background within the image, similar to the Gestalt processes of visual perception.

The semantic level refers to the identification of the image in the illustration, relating to visual perception theories described in Chapter 2. The lines differentiated from the background can be recognised as meaningful shapes as described by Gombrich (1990), Gregory (1990), Willats (1997).

The pragmatic level requires interpretation of the image by the viewer, again relating to theories of visual perception described in Chapter 2. For example, the combination of shape and background allow contextual inference to be implied from the lines within the image.

The semantic and pragmatic levels require knowledge of the shapes that are in the image and are also, to an extent, dependant on cultural and experiential factors for their interpretation, as described by Kress and van Leeuwen (1996), Mirzoff (1999), and Sturken and Cartwright (2003). The theories of visual perception described in Chapter 2 offer plausible explanations of the manner in which images are viewed and interpreted in terms of the interpretation of the relative position of lines and shading. The fact that this analysis system embraces many of the aspects described by these theories seemed to be a valid reason for its use in this study.

Onto these three semiotic levels are grafted visual factors which add further layers of interpretation, unity, location and emphasis. Unity refers to areas in the illustration which are separate entities. Location is the spatial arrangement of entities within the image and relates to factors of size and scale. Emphasis is the hierarchical arrangement of entities in an image, where the more important entities are clearly visible and those of less importance, less or partially visible.

In addition to the visual factors, the text accompanying the illustration is accounted for by a level of text parallel. The text can add information by explanation, making clear aspects of the image which are not immediately obvious, explaining aspects which are not represented but are implied or be descriptive and describe the image without adding further any information.

These levels are presented in a grid formation enabling the levels, visual factors and text parallels to be cross referenced. This offers a number of categories to apply to an illustration (Table 4.3).

Linguistic / Visual	Syntactic	Semantic	Pragmatic
Unity	Perceives groups of marks as an entity	Recognition of entity with the aid of relevant details	Familiarity with situation enables recognition
Location	Depth cues without meaning	Recognition of the relation of parts via physical cues	Familiarity with situation enables recognition of structural relationships
Emphasis	Attention directed by sensory factors	Attention directed by human experience	Attention directed by cultural conventions (e.g. colour coding)
Text Parallels	Physical relationship of text and images	Naming consistency and mapping between image and text	Familiarity with situation allows text parallel to work

Table 4.3 The Goldsmith analysis grid.

Goldsmith's intention was to apply the grid to pages in books, to assess the levels of information made available by the combination of text and image. This would, she proposed, enable pages to be produced that carried no intentionally hidden or ambiguous meaning. The grid was initially used in the pilot studies for this study to analyse the layers of information available to a viewer in the book illustrations used as prompts during interviews. An example of the use of the grid is presented below to analyse the representation in Figure 4.1.

Image redacted due to third party rights or other legal issues

[redacted]

Figure 4.1 Seasonal change (Tahta 1990) pg 8

Applying the Goldsmith analysis to the illustration in Figure 4.1 the syntactic unity level can be seen as a circle and a partial circle. These shapes are apparent even if the viewer did not know what they were intended to represent. There are also three yellow quadrilaterals from left hand edge of the page to the edge of the large circle. There are areas of different colour and a dashed line on both the whole and partial circles.

At the semantic unity level, the circles are recognisable as spheres because of the slight shading at the edges and point of light on the small circle.

The pragmatic unity level requires the viewer to know about the appearance of the Earth from space. This could reasonably be assumed to be the case as the image is used widely in many settings, but its recognition will be dependant on the age and experience of the viewer.

The syntactic location level is the area of slight shading and bright spot on the smaller circle. This is a depth clue to the shape, implying a spherical shape. There is no shading apparent on the larger circle.

The semantic location level has no scale clues and there is no relationship between the parts of the image.

At the pragmatic location level, the yellow quadrilaterals need a degree of scientific knowledge to understand that these are rays of light from the Sun and there are more than three rays emanating from the Sun, so this level is potentially open to misinterpretation. An understanding of the incidence of light at a curved surface is also needed to interpret the representation of the 'rays' striking the Earth's surface.

The syntactic emphasis is the representation of the Earth, depicted in shades of colour, blue for the seas, greens, yellows and beige for the land-masses.

The semantic emphasis level requires the viewer to recognise the green/yellow/beige areas of colour as particular masses, in this case the western African coast and the eastern South American coast.

The pragmatic emphasis level requires the understanding that landmasses are generally represented by the colours used and that light rays are conventionally represented by straight yellow lines.

The text parallels add information to the image. At the semantic level, labels are placed on some of the items in the image. At the syntactic level, they inform the viewer of their intended representation, as in the 'rays' from the Sun. At the pragmatic level, the 'rays' and their incidence with the surface of the Earth are explained in terms of the three rays shown and the variation in heat felt at the point of incidence.

These aspects are entered into the grid in Table 4.1.

Seasons	Syntactic	Semantic	Pragmatic
Unity	Circle and part circle yellow oblongs dotted line	Shading implies spherical shape	Need to be familiar with the view of Earth from space exploration and geographical globes
Location	Land masses	Different spread of rays at different parts of surface	Need to be familiar with the fact that a ray will behave differently on a curved surface from a flat surface
Emphasis	Colours of land masses, sea and clouds	Clouds on larger sphere Equator marked	Rays striking Earth's surface immediately noticeable
Text Parallels	Text for each ray shown	Tilt explained Rays labelled North and South poles indicated Hemispheres indicated	Effect of the curved surface and rays explained in terms of heat

Table 4.4 Goldsmith analysis of Figure 4.1.

The illustration is relatively straightforward to interpret by a knowledgeable viewer. The analysis grid allows the missing information to be assessed. In this case without the text, the blocks of colour representing the rays would have little meaning. The text also explains that rays come from the Sun, and it is assumed that the Sun is producing the rays shown, even though the Sun is not shown. The rays are shown parallel to each other, assuming knowledge of the behaviour of light.

It is also assumed that the representation of the Earth is known; though the Earth is also named in the text, the assumption is that the viewer knows to which object the text refers. The textual explanations accompanying the 'rays' describe the incidence at the Earth's surface. As this is a depiction of the seasons, this is done in terms of heat, because this is one of the most obvious factors of difference between the seasons (summer is hot, winter is cold). The tilt of the Earth and the role that this plays in the changing seasons is referred to in the text as making the Earth lean towards the Sun. This is misleading and possibly reinforces the commonly held misunderstanding that it is the proximity of the Earth to the Sun that increases the temperature during the summer months, and vice versa in the winter. Though the text explains the difference between direct rays and indirect rays, the rays are depicted as yellow, implying via convention that the rays represent sunlight. The angle of incidence at a curved surface refers to light yet the text explains this in terms of heat. Therefore, to interpret the image the viewer has to know that the Sun's energy consists of light and heat.

The hemispheres are labelled North and South by reference to the 'top' and 'bottom' of the Earth. This has implications for understanding other scientific concepts particularly that of gravity, where a common misunderstanding is to assume that gravity acts 'downwards', rather towards the centre of the Earth.

Therefore, though this image contains many of the factors involved in seasonal change, much of the information relies on existing knowledge and accurate interpretation of the elements of the images in the illustration.

The Goldsmith grid was used to analyse illustrations from books used as prompts during interviews. It was also used to analyse the diagrams constructed on the board during lessons. A board diagram could be viewed in the same way as an illustration in a book, as containing images and text. The teacher constructed the diagrams piece by piece, talking the children through each element as it was added. The teacher's speech was added to the text parallel level, in addition to any text on the constructed diagram. The teacher used diagrams in text books as a basis for the construction of the board diagrams. These diagrammatic illustrations from books were also analysed. This allowed a comparison between the board and book diagrams, enabling aspects added or omitted by the teacher to be made clear.

In the same way the concrete models used by the teacher could be analysed using this system, with the verbal explanations and additions being classed as textual accompaniment. Therefore all the representational material employed by the teacher could be analysed using this system.

In addition to the levels of informational content relating to the relationship of image and text/verbal explanation, the structures, behaviours and mechanisms, integral to understanding how the represented systems operated, form an important part of representational material.

4.3.2 Science in representations

So, in addition to the Goldsmith grid, a further analysis system was used. Whilst the Goldsmith grid facilitates the analysis of constructed images or models in terms of the elements of their construction and the perceptual interpretation of those elements of construction, in combination with textual accompaniments, it does not account for the scientific aspects of representational material. The system developed by Buckley and Boulter (2000) allows the scientific aspects of representation to be assessed.

The Buckley and Boulter grid was developed from theories of mental models and the contribution they make to the teaching and learning of science (Gilbert and Boulter 2000). The theory of mental models has been described in detail in Chapter 2. In brief, mental models represent personal understanding of scientific phenomena. Expressed models can be seen as personal explanations of mental models. In order for a mental model to be a complete understanding of a phenomenon, it needs to have all the elements proposed by Buckley and Boulter (2000), the structure, behaviour and mechanisms, present in its explanation. These elements, the structure, behaviour and mechanism, where structure is the structural parts and their spatial relationships, behaviour is the time-based processes and changes and the mechanism is the interaction of the time-based processes giving rise to the behaviour of the whole system, are important for understanding illustrated phenomena. These elements were extracted from the book illustration above and put into a grid (Table 4.5).

Structure	Behaviour	Mechanism
Large partial circle Smaller complete circle Yellow oblongs – rays Dotted line – equator Hemispheres Poles	Rays at circle edge – different spreads Tilted Earth	None

Table 4.5 Buckley and Boulter analysis of Figure 4.1.

In order for a particular phenomenon to be understood, all aspects of structure, behaviour and mechanism must be present. It can be seen from the analysis above that the mechanisms that are operative in seasonal change are not present. Therefore, the illustration is incomplete as an explanation of the factors involved in seasonal change. A diagram constructed on the board to illustrate seasonal change can be analysed using this system and the talk and gestures, employed while discussing the elements of the diagram as they are added, allocated to one of the categories.

4.3.3 Using the analysis grids in this study

The combination of the two analysis grids gives a view of the amount of information available in representations used during teaching. The grids can be used with any format of representation, for example, illustrations from books, physical models used during demonstrations and diagrammatic constructions on the board. In this sense, the combination of the two grids is a powerful tool for analysing the informational content of every aspect of using representational material in a lesson, as the teacher's input in terms of gestures and accompanying explanations can be included.

Used individually, the grids allow analysis of the information available not only in texts and board diagrams, but also in conversations and explanations, resulting from the interviews with the children and the teacher and the recordings of the series of lessons. The Buckley and Boulter (2000) grid enables aspects of the expressed models to be highlighted, thereby, giving an insight into the speaker's mental model of the phenomenon under discussion. In the case of the teacher, the combination of the analysis of the interview, diagrams on the board, explanations and demonstrations to the children, allows a reasonable picture of the mental model being used to formulate the lessons. Data from the video recordings of the lessons were compared with data from the audio recordings of the interview with the teacher to determine the consistency of the practice with the expressed views.

4.4 Summary

The large amount of recorded data collected from the classroom was reduced through transcription coding and analysis to meaningful and manageable proportions to determine the parts of the data which would efficiently and reliably answer the questions posed. The incidents of representational use in the science classroom were analysed in terms of their position in the lesson, the type of representation used and the way the teacher used the representation with the children. The methods used to analyse all the material from the lessons were selected to be as systematic and objective as possible. The results of the analysis and their contribution to answering the specific research questions posed for this study are discussed in detail in the following chapter.

Chapter 5

The Results

5.1 Introduction

The focus of this study was to examine a teacher using representations in primary science lessons. This was achieved by observing a teacher teaching a whole science topic. Extended access to a primary science classroom allowed observation of a whole teaching series enabling the type and development of representational material used by the teacher to be noted in the context of each lesson and of the series of lessons. Once the use of representational material had been noted, through the video recording of the teacher's activities in the lessons, each incidence of use could be analysed in terms of its place in the lesson and the series of lessons.

The methodology selected for the study to an extent determined the analyses which could be performed on the data collected. The video recordings of the lessons gave the data for the teacher's use of representations in the lesson. As discussed in the previous chapter, the analysis applied to this data was interpretive in that activities from the lessons were allocated to categories which arose from the lessons themselves.

The interview with the teacher gave data about the choice of representations used in the lesson. The video recorded material also gave an idea of the teacher's pedagogy, in addition to those ideas expressed in the interview, as it was a record of the teaching that actually occurred in the series of lessons. As the use of representations was also recorded during the series of lessons, the materials used and the way they were used enabled analyses of all the representations.

The topic of the series of lessons was The Earth in Space. As has been previously discussed in Chapters 2 and 3, this topic is often regarded as difficult to teach. One of the main reasons for this is the scientific knowledge of the interactions of the bodies in the Solar System required to explain everyday observations such as day and night. Also significant are the technical difficulties of illustrating such large scale phenomena in the classroom and the resulting dependence on models and illustrative materials. Therefore the data collection was designed to capture all incidences of use of representational material made by the teacher.

The data collected provided the following information:

- An overview of the series of lessons – video
- A count of the amount of use of representations in individual lessons – video
- A count of the use of representations over the whole series of lessons – video
- The teacher's ideas about teaching and learning – teacher interview
- The teacher's ideas about the topic – teacher interview
- A general overview of the children's ideas about the topic – children's interviews
- An indication of any changes in ideas from the teaching of the lessons – children's interviews
- The informational content of the representations used in the lessons – analysis grids
- A comparison with the teacher's ideas and the actual content of lesson – teacher interview and video of lessons
- A comparison between the teacher's board diagrams and the diagrams drawn by the children in their exercise books – stills from the video and pages from exercise books.

The setting for the lessons is described to give context to the study situation. The results of the data analysis are presented as an over view of the lessons. The use of representational materials is described in detail for each lesson. Presenting the results in this way shows how each representation was introduced to the children as the topic was developed by the teacher. It also shows how the subsequent representational material was related to previously used material. The issues raised by the research questions are referred to in the description of results from each lesson and discussed in detail in the following chapter where they are addressed individually, question by question.

5.2 The setting

The study school has been called Southfield, and was an independent school in the London area catering for children from 3 – 18 years of age. In the school was divided into departments referred to as houses: reception, infants, juniors and seniors. Each department had its own separate set of buildings, with some shared areas such as games facilities, dining hall and assembly hall. The children in the study were in the junior house for children from Year 4 (ages 8 – 9) to Year 6 (ages 10 – 11). Most of the children in the study had been in the school since reception class and were therefore familiar with the school, its layout, ethos, routines and staff.

Science lessons took place in a large room in the junior house designated the science lab, where there were free standing tables and stools in the centre of the room and fixed benches with gas and electricity supplies around the external walls. The free standing tables and stools were always arranged in three rows facing the white board, with two sets of two tables and stools at right angles to the board at either side of the room. The children were generally allowed to choose where they sat each lesson. Exercise and textbooks were stored in the lab, except on the evenings when the children had homework to complete.

Science lessons for the Year 5 (ages 9-10) group consisted of 2 hours of lessons timetabled for two periods of approximately one hour each, on two days of the week. The series of lessons covering the topic of the Earth in space took place over a period of eleven weeks; the individual topics for the lessons are shown in Table 5.1. The series was not continuous, with interruptions to lessons for holidays (Easter, 3 lessons; half term, 2 lessons), teacher illness (1 lesson) and a residential trip (2 lessons).

The study teacher was a biology graduate with responsibility for the science curriculum in the infant and junior houses and at the time of the study taught most of the science lessons in both houses and also taught science in the senior house for Years 7 – 9 (ages 11 – 14). This situation was due to change as class teachers were to undertake some of the science teaching for their own classes, as a result of a thinking skills initiative introduced through the school. The situation at the time of the study involved the study teacher teaching science in parallel with the class teacher for the other similar sized Year 5 class. Lessons were mutually planned and taught in the same week so that the same material was covered by all Year 5 children in the same time period.

Lesson	Subject
1	The Solar System
2	Order of the planets
3	Distances between planets
4	Sizes of the planets
5	Computer research
6	Computer research
7	Relative sizes of Earth, Sun and Moon.
8	Day and night
9	Seasons
10	Graphs
11	Graphs + table and some Moon phases
12	Phases of the Moon

Table 5.1 The series of lessons – topics.

The school's rules of conduct required the children to sit in silence in lessons except when they were invited to contribute. Teaching in all parts of the school tended to be traditional and didactic; the teacher talked and handed out exercises whilst the children sat and listened and completed the set exercises. Children were required to put up their hands when they wanted to speak and opportunities for discussion and expression of ideas were relatively limited. All teachers in the junior school situated themselves in front of the white board and stood in front of the children to teach. Questioning tended to be direct, with the teachers selecting the children to answer. The teacher, though embracing the school's ethos of quiet control, was relaxed in demeanour and responsive to the children, with a quiet, pleasant and well-modulated voice, and occasionally responded to interruptions in the lessons and engaged in asides and jokes with the children.

In order to preserve the anonymity of the teacher, children and school, neither the teacher nor the children have been assigned gender. Though gender considerations are undoubtedly influential in science teaching and learning, their effects have not been considered as part of this study (Whyte 1986, Murphy 1997, Marsh 1998, 2000).

Each lesson was analysed in detail to determine the amount of time spent using representations. During this analysis, it became apparent that there was a distinct pattern followed for each lesson. The activities that occurred in most lessons were assigned a category. Often activities overlapped, so the main activity during that period became the designated activity of that period. The ten categories to which activities in the lessons were allocated were described in Chapter 4.

Dividing the lesson into categories in this way gives context to the organisation of the lessons in general terms and allows the periods of representational use to be seen in the context of the overall activities likely to occur in each lesson.

The total time of the lessons over the course of the topic was 13 hours 32 minutes and 10 seconds. The lessons were timetabled to be of the same duration but in reality varied in length from just under 1 hour to 1 hour 16 minutes with an average lesson time of 67 minutes 41 seconds. The total time for each category of activity per lesson is given in Table 5.2.

Category	Lesson											
	1	2	3	4	5	6	7	8	9	10	11	12
Duration (m:s)	61:08	67:54	76:06	74:50	59:59	64:49	72:00	70:32	74:07	67:03	69:14	54:28
Settling down	2:51	1:44	0:43	1:35	0:54	2:34	6:30	3:02	4:48	2:38	1:17	0:54
Recapping	0	3:07	11:17	0:37	2:55	8:41	2:10	7:42	7:06	0:31	19:46	4:08
Introduction	1:03	5:49	0	0:37	2:48	0	2:42	3:02	2:18	2:57	1:13	3:21
Questioning	2:02	0	0	0:18	2:04	0	8:56	0	0	0	0	4:48
Explanations	38:09	1:14	2:24	18:24	13:29	0	3:27	4:03	9:22	38:09	0	5:24
Representations	14:53	30:07	12:50	3:02	0	0	17:38	28:25	30:15	0	0	16:14
Giving out	0	0	0:20	0	2:34	0	0	2:52	0:53	0:55	0	2:14
Writing on the board	0	14:44	0	0	4:36	0	13:54	8:33	8:37	0	0	7:24
Working on own	0	11:09	40:50	43:48	29:16	50:17	14:26	11:05	9:40	21:28	45:34	8:03
Closure	2:10	0	7:42	6:39	1:23	3:17	2:17	1:48	1:08	0:25	1:24	1:58

Table 5.2 Time taken in minutes and seconds for each activity in lessons.

The amount of time for each activity has been summed and is presented in Table 5.3.

Category	Total Time (m:s)
Settling down	29:30
Introduction	25:50
Questioning	18:08
Explanations	134:05
Representation use	153:24
Giving out books and equipment	9:48
Children working on their own	285:26
Writing on the board	57:48
Recapping	68:00
Closing the lesson	30:11
Total	812:10

Table 5.3 Timings for activities in all lessons in minutes and seconds.

With the lessons divided into broad categories, as above, it became easier to ascertain for how much of each lesson, and of the total lessons, the teacher had used representations with the children. Categorising the lessons in this way gave each activity a context within individual lessons and as part of the overall series of lessons. Though there were differences in the categories of activities during each lesson the overall pattern to the lessons was relatively stable. Generally, the children came into the science lab and selected their seats, the teacher recapped on the previous lesson and introduced the topic for the current lesson. The practical activities were explained and any equipment and books handed out. The children completed the activities and at the end of the lesson there was a closing period where the children were given instructions to deal with the materials they were using, occasionally a recap of activities and usually an indication of what was to be covered in the next lesson.

5.3 Activities in the lessons

Each lesson started with the children settling down in their seats. This was a quietly chatty time and gave the children the opportunity to connect with those in adjacent seats (the seating was liable to be different every lesson as the children were allowed to sit wherever they wanted).

Once all the children were present and seated, the class was brought to order by the teacher standing in front of the class and attracting their attention verbally. This sometimes took several attempts (this time was included in the settling down time). Once attention was directed towards the teacher, there was a recap of the activities and points covered in the previous lesson and an introduction to the topics and activities of the current lesson. Any books that were needed immediately would be given out. If the lesson was to be practically based, the introduction was usually followed by a period of explanation of the activities and the required equipment given out. Occasionally periods of explanation were interspersed with periods of questioning about the explanation.

Explanations have been classified as those periods when the teacher stood in front of the class and talked. Occasionally questions were asked by the teacher during these explanations but they tended to be closed questions, addressed to one child who was selected to supply the answer. The children were required to sit quietly and listen during these periods.

Explanations were often followed by a period of writing on the board. The children frequently started to copy as the teacher wrote, but time was given for them to catch up. This 'catching up' time was classified as children working on their own. The copying of written notes from the board has not been included in the representation category as there was no explanation given and the teacher only occasionally referred to what was being written as it was written. The board work was effectively notes about the preceding activity or explanation.

When the children were involved in practical activities, they were working either independently or in pairs, with the teacher circulating the room assisting as necessary. This was classified as children working on their own. This was the activity which occupied the largest amount of time. This is to be expected in science lessons as investigations form a large part of science learning, except that the activities that these children were engaged in were not investigative activities. Most of this activity took place in the two computer research and two graphing exercise lessons.

The category 'representation use' includes all incidences of the use of representations where the teacher used either physical objects or diagrams on the board as demonstration or explanation of an aspect of the lesson. The inclusion of diagrams in this category is appropriate because the diagrams drawn on the board were built up with the teacher talking about the elements of the diagram as they were added. The explanations that accompanied the construction of diagrams have been included in the representation use time, as they are pertinent to and dependant on the representation being constructed.

Every lesson (with the exception of the second lesson) ended with the teacher bringing the class to order and commenting on the children's achievements and what was proposed for the next lesson. This gave the children feedback on their activities and allowed them to anticipate the next lesson. It also put the lesson into overall context.

5.4 Details of representational use

The 'representational incidents' were deemed to be those times during the lessons where the teacher used some form of visual representation. These incidents were isolated from the other observed activities. These periods of representational use were timed for the whole period of lessons. The periods of use are presented in Table 5.4.

Lesson	Time using representations (m:s)
1	14:53
2	30:07
3	12:50
4	3:02
5	0:00
6	0:00
7	17:38
8	28:25
9	30:15
10	0:00
11	0:00
12	16:14

Table 5.4 Periods of representational use per lesson in minutes and seconds.

The types of representations used were varied, so the types of visual representation were given a category to denote the mode. The modes of representation used by the teacher with the children were:

- diagrams on the board
- worksheets
- poster
- textbooks
- physical objects – e.g. balls and torch
- concrete models.

The individual modes of representational use were timed for each occurrence. These times are in Table 5.5.

Lesson	Representation	Duration (m:s)
1	Brainstorm – board diagram	14:53
2	1 Board diagram of sheet 2 Measuring on field	6:17 23:50
3	1 String model	12:50
4	1 String model 3 Poster	2:08 0:54
5	Computers	
6	Computers	
7	1 Selection of spheres 2 Demo relative sizes, Earth, Sun and Moon 3 Day demo 4 Year demo 5 Day and night demo	2:40 6:27 0:58 0:24 7:09
8	1 Day and night 2 Path of Sun diagram 3 A year	10:34 14:57 2:54
9	1 Globe and torch - day and night 2 Globe 3 Beach ball and bead – tilt of Earth 4 Beach ball and globe – seasons 5 Board diagram - seasons	2:07 2:42 8:08 7:23 9:55
10	Graphs	
11	Graphs	
12	1 Globe and torch 2 Board diagrams	2:06 14:08

Table 5.5 Duration of representational use per lesson in minutes and seconds.

The periods of representational use involving the construction of graphs and computer research were not included in the results as they did not involve the teacher, except for a brief explanation of the task, and therefore were not deemed to be representational use as defined for this study.

Each episode of representational use was analysed using the Goldsmith (1984) and Buckley and Boulter (2000) analysis grids, described in detail in Chapter 4. Initially the representation was analysed on its own and then re-analysed to include teacher additions such as gesture and verbal explanations. This enabled the informational content of all the representations used to be determined as individual entities and with teacher additions. The results of the analyses of representations will be presented in a lesson by lesson format, in the order in which they were presented to the children in the series of lessons.

5.5 The lessons

The amount of time the teacher spent using representations with the children was 18.9% of the whole teaching time. Each instant of the use of representations will be discussed in detail in the context of the lessons where they occurred.

5.5.1 Lesson 1

The first lesson consisted of a period of revision of a previous test and the collection of the children's ideas about the contents of the Solar System as lists on the board. This activity the teacher termed 'brainstorming'. Technically this was not accurate, as brainstorming is the collection of ideas, any ideas, which might be associated with the topic in question (Child, 1993). This could include objects outside the Solar System, if that was the children's understanding. In reality, the children were attempting to guess the contents of a list the teacher had previously created. However, as some answers were objects outside the Solar System, this was acknowledged and dealt with by the teacher constructing a separate list on a different part of the board. The result was four lists Figure 5.1. Appendix VIII contains stills of the board diagrams taken from the video recordings of the lessons.

		Planets	
	Meteors	Mercury	
	Star	Pluto	
	Sun	Saturn	Empty space
Black hole	Moons	Jupiter	
Milky way	Weather satellites	Earth	
Galaxy	Rockets	Uranus	
Aliens	Space debris	Neptune	
	Comet	Mars	
	Asteroids	Venus	

Figure 5.1 Lists as they appeared on the board.

Analysis of the lists shows that the structure of the Solar System is made available to the children as the two central lists. The structure is presented in two parts, the planets and the other objects. Those objects that are outside the Solar System are in a separate list, reinforcing their position outside the Solar System. Towards the end of the lesson the teacher asked the children what was the main component of the Solar System, and eventually receiving the answer that was sought, empty space, stressed this by putting it in a different part of the board in a list of its own.

There is no mention of the order, position, shapes or sizes of the objects. This is a naming exercise and familiarises the children with the contents of the Solar System and those objects outside its boundary. There is no indication of any behaviour or interactions of the objects nor of the mechanisms which delineate the Solar System as being an entity.

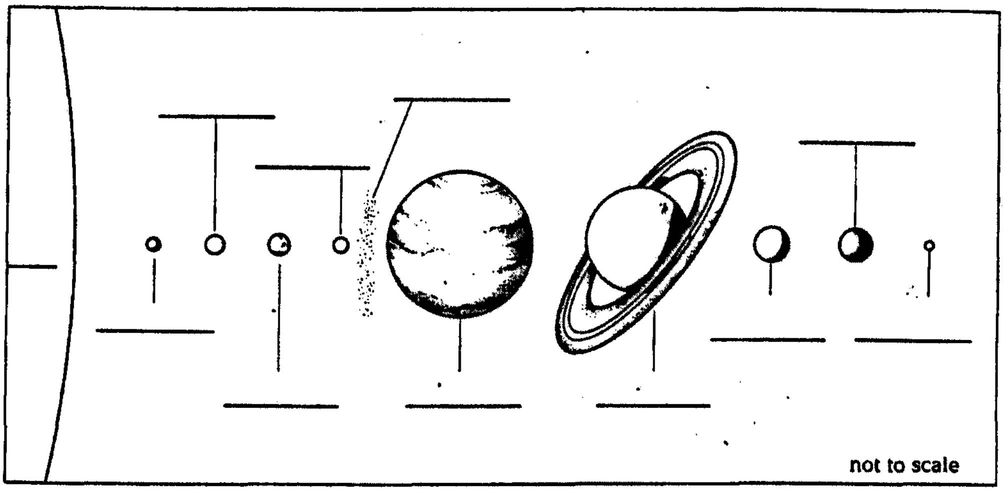
The teacher's gestures, repeated expansive gestures with both arms, which were made during the lesson when the teacher mentioned the Solar System, could have suggested to the children that the structure of the Solar System might be circular and finite, but this was not expressed in words.

5.5.2 Lesson 2

The second lesson followed up the naming exercise carried out in the previous lesson by placing the planets in the order they occur from the Sun outwards. This was initially in the form of a worksheet (see Figure 5.2)

The sheet was introduced to the children and the method for filling it in explained. The children worked independently, filling in their own sheet. The teacher then redrew the sheet on the board and took the children through the answers step by step. The children were encouraged to put a small tick beside each planet they had written in the right order. Analysis of the sheet shows that only structural aspects are present but the teacher added a behaviour with an arm gesture when referring to asteroids 'floating around' (Table 5.6). A second analysis, which included the words and gestures the teacher added as it was completed during the re-drawing on the white board (Table 5.7).

Activity 7L.5a The Solar System



The passage describes the Solar System. Use the passage to help you fill in the labels on the diagram.

At the centre of the Solar System is the **Sun**. All of the planets orbit the Sun.

The closest planet to the Sun is **Mercury**. Mercury is a very hot planet.

Next to Mercury is **Venus**. It is the closest planet to **Earth**, where we live.

The fourth planet from the Sun is **Mars**. These first four planets are called the **rocky planets.**

In between Mars and Jupiter is the **asteroid belt**. This is made from thousands of lumps of rock.

Jupiter is the largest planet. Next to Jupiter is **Saturn**. It has rings which are made of orbiting dust and ice.

The next two planets are called **Uranus** and **Neptune.** Jupiter, Saturn, Uranus and Neptune are called the **gas giants.**

The planet that is furthest from the Sun is called **Pluto**. It is made from ice or rock.

Figure 5.2 A worksheet from lesson 2.

Structure	Behaviour	Mechanism
Sheet Eight circles of different sizes in a line Angled oval on seventh circle Shading (implies depth) Large arc labelled Sun Correct order from Sun (names) Not to scale for – distance – size Order of planets from Sun		

Table 5.6 Analysis of the worksheet – Buckley and Boulter.

Structure	Behaviour	Mechanism
Sheet Eight circles of different sizes in a line Angled oval on seventh circle Shading (implies depth) Large arc labelled Sun Correct order from Sun (names) Not to scale for – distance – size Order of planets from Sun		
Talk "Almost looks like a straight line it is so huge" (Sun)		
"Those four together, Mercury, Venus, Earth & Mars are called the rocky planets"	"Floating around" indicated by waving hands (asteroids)	
"Big rings around it" (Saturn)		
Gesture Points to the sun and planets as they are mentioned.		

Table 5.7 Analysis for the worksheet with teacher additions – Buckley and Boulter.

Using the Goldsmith analysis, described in detail in Chapter 4, for the worksheet reveals that there are several layers of information absent. (Table 5.8)

Visual \ Linguistic	Syntactic	Semantic	Pragmatic
Unity	Nine circles one circle with surrounding ellipse small dots line	Different sizes	Line indicates relatively enormous Sun.
Location	Some shading		Nine planets in the Solar System
Emphasis			
Text Parallels		Names and positions of planets	Orbit mentioned but not defined Saturn has rings Jupiter largest planet

Table 5.8 Analysis of the worksheet with teacher additions – Goldsmith.

Once the children had finished this exercise, the class went outside to the school playing field (this activity was not filmed, but the researcher accompanied the class). The teacher had large pictures of the planets and the Sun and a trundle wheel for measuring distance. The teacher allocated one child the picture of the Sun and stood them at the farthest point from the school. The distances of the planets from this Sun were then measured with the wheel. These were scaled measurements of the distances between the planets, calculated by the teacher before the exercise. This activity is suggested in the teacher's book from the Spectrum scheme (Cooke and Martin 2004). The pictures of the planets were not to scale. The distance between the 'planets' were measured to scale with regard to distance but not to the 'size' of the planets. As the school grounds were not large enough to measure out the distances in a line, the furthest planets were difficult to locate, due to the restrictions of space in the school grounds, so the positions of the furthest planets were estimated.

In both activities in this lesson analysis shows that all the references to the Solar System were structural. No extra information was added by the teacher's interpretation of the worksheet or the exercise in the school grounds. The representations gave the children reinforcement of the structures of the Solar System, by naming all the parts and their relationships in terms of the order in which they occur in the Solar System, and referring to some of their properties by measuring the distances between the planets and the Sun.

5.5.3 Lesson 3

The activity in the third lesson consisted of making a model of the planets in the correct order from the Sun and the appropriate scaled distances apart (Figure 5.3) and reinforced the facts that the children had been given in the previous lesson with regard to the order of the planets and their relative distances apart.

Analysis of the completed model (Table 5.9) does not contain any references to the behaviour or mechanism of the Solar System. It is again a naming and ordering exercise, though the finished model does give a scaled impression of the distances between the planets and the groupings of the inner (Mercury, Venus, Earth and Mars) and outer planets (Jupiter, Saturn, Neptune, Uranus and Pluto), which the teacher had referred to at the beginning of the lesson.

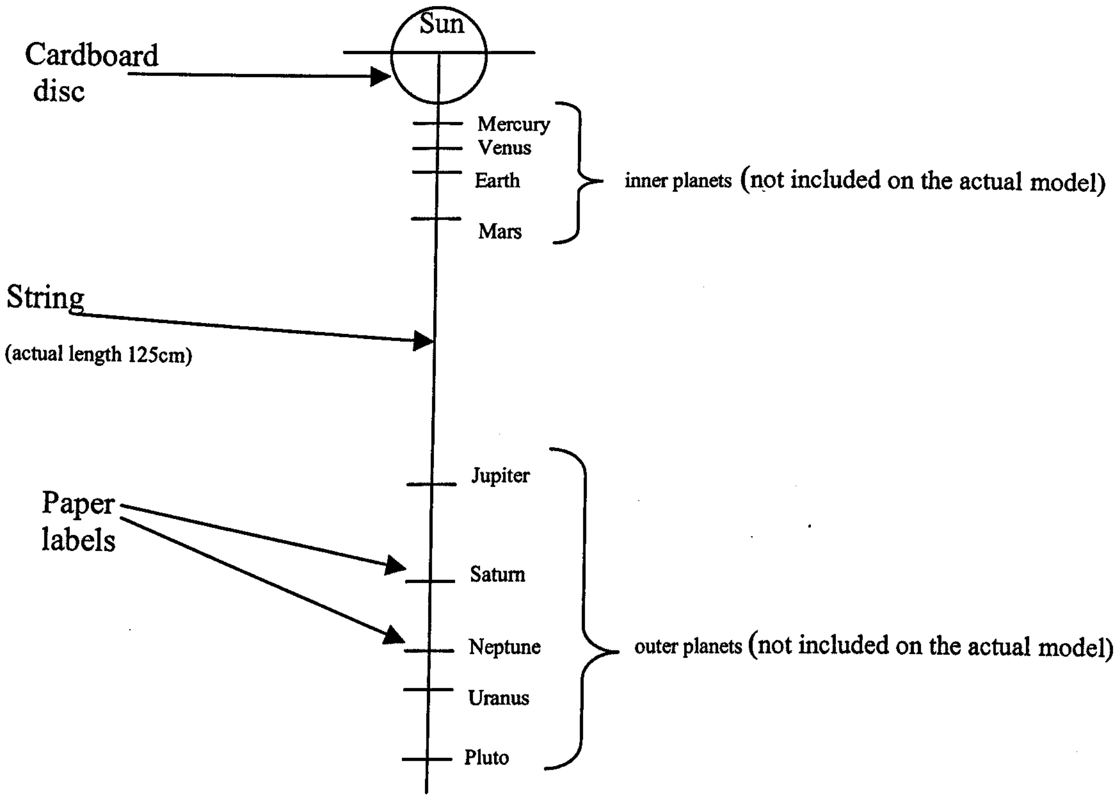


Figure 5.3 A sketch of the string model of the distances between planets – the spaces between the planets are not to the scale of the actual model.

Structure	Behaviour	Mechanism
Cardboard circle – marked Sun Eight 'tabs' along the string Planet names on 'tabs' Correct order and relative scale from Sun Groupings of inner and outer planets discernable		

Table 5.9 Analysis of the string model – Buckley and Boulter.

The teacher added little to the model by verbal explanation or gestures other than to indicate the planets on the string as their names were spoken aloud and the groups of inner and outer planets by pointing at the groups (indicated in the sketch).

5.5.4 Lesson 4

The fourth lesson was the construction of a model to show the relative sizes of the planets. An extensive explanation of how to draw the circles to represent the respective planets followed an explanation of the enormous size of some of the planets, in actual dimensions. The circles were fixed together to form a 'fan' of planets in order of their relative sizes.

A wall poster (Schofield and Sims 2003) was put up towards the end of this lesson which gave the children ideas about the colours of the planets (Figure 5.4). The teacher referred to this poster only to highlight the red spot on Jupiter and to encourage the children to include this in their work, though it was also available for the children to use as a reference for planetary colours. An example of a finished fan model is Figure 5.5. Analysis of the wall poster (Schofield and Sims 2003) and the finished fan models, using the two grids shows that only information about the colours of the planets was added to any other information the children had already been given (Tables 5.10, 5.11 and 5.12). The order of the planets was given in the poster but due to the spatial organisation, this did not appear to be the same as the previous representations. Orbital paths were marked on the poster but no direction was indicated. The fact that the orbits were indicated as lines means that they were represented as structures rather than behaviours.

Linguistic / Visual	Syntactic	Semantic	Pragmatic
Unity	Nine different sized circles – three with additional marks One partial circle Curved white lines	Colours for planets Sun orange/red	Knowledge of planet colours allows recognition
Location	Some shading denoting dimension	Planets in order from Sun	Knowledge of order from Sun needed to recognise planetary positions
Emphasis			
Text Parallels	Details of physical attributes	Planet names	

Table 5.10 Analysis of the wall poster – Goldsmith.

Structure	Behaviour	Mechanism
Planets Colours Different sizes – not to scale Curved, elliptical lines indicating orbit Details of planets, physical attributes		

Table 5.11 Analysis of the wall poster – Buckley and Boulter.

Structure	Behaviour	Mechanism
Different size cardboard circles – to scale – to represent the planets Colours Ordered by size of circle Planet names – on circles		

Table 5.12 Analysis of the finished fan model – Buckley and Boulter.

So far, representations, accompanied by speech (talk) and gesture were included in all the lessons. The children only had access to information about the contents, size and order of the bodies in Solar System; no indication of movement; relative position or interaction of the structures had been indicated.

5.5.5 Lesson 5 and 6

The fifth and sixth lessons did not make use of any further representations, as defined for this study, in that the teacher did not use representational material with the children. These lessons were computer research, where the children worked in pairs in the computer room looking for information on the objects the teacher had identified as being outside the Solar System. The children were given a list comprising, black holes asteroids, galaxies, empty space, comets, stars and the Sun, from which they could choose two objects. None of the children questioned this list of objects for which they were expected to produce a picture and writing by cutting and pasting from the web sites they accessed. The computer work and the sites the children accessed were not recorded or analysed for this study as this was work the children completed independently and therefore there was no teacher input other than to help with technical difficulties caused by the slowing down of the school's server.

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Figure 5.4 The wall poster (actual size – 77 x 53 cm).

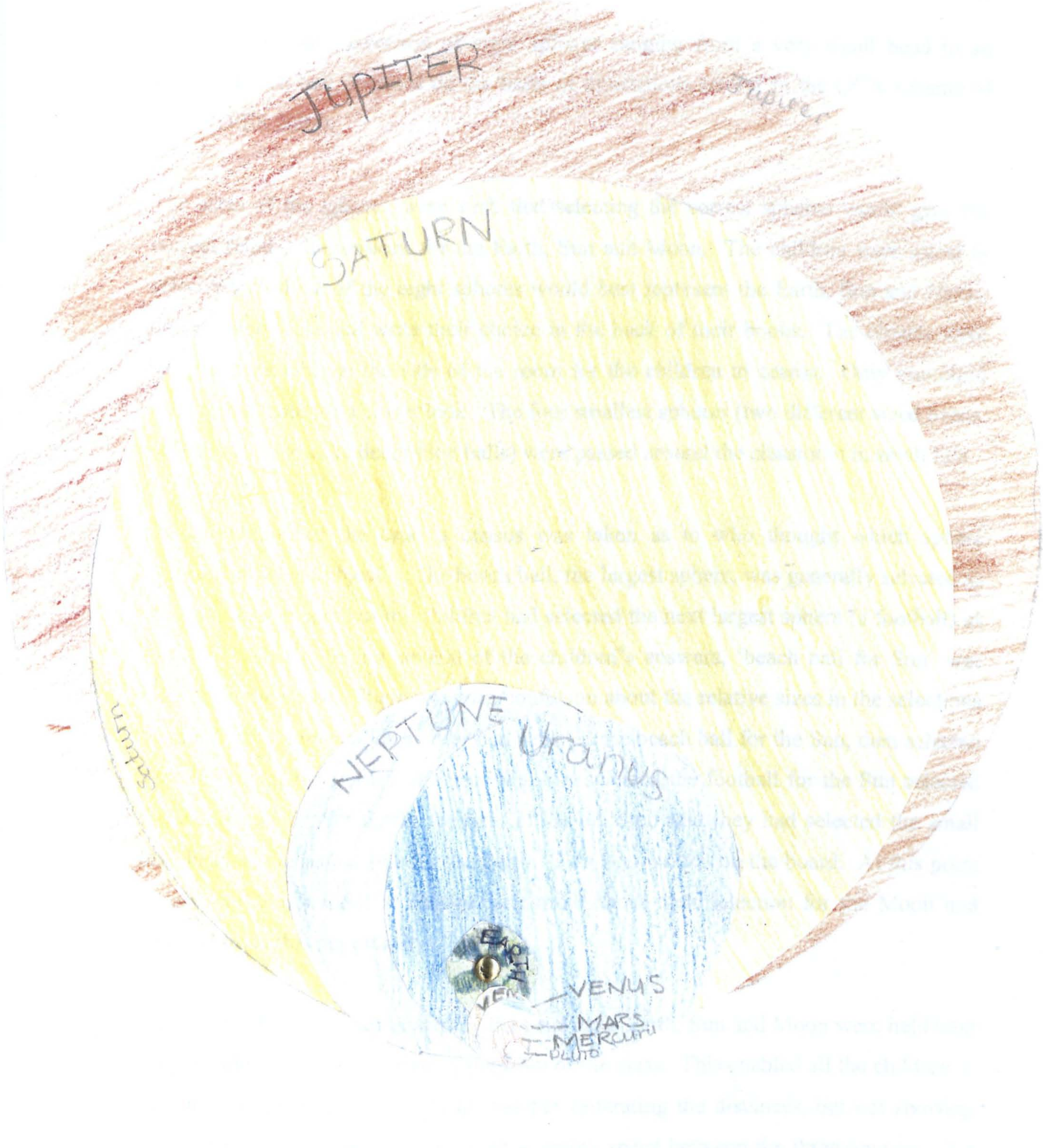

Figure 5.5 The 'fan' model activity (Scale: Uranus, diameter = 21cm)

5.5.6 Lesson 7

The seventh lesson moved the children from the objects in the Solar System to considering specifically the Earth, Sun and Moon.

The teacher had a selection of eight spheres ranging from a very small bead to an inflated beach ball, selected on the basis of dimensions set out in the QCA scheme of work (DfES 2005).

The sizes of the spheres were such that selecting the correct spheres would give the correct relative dimensions for the Earth, Sun and Moon. The children were asked to select which three of the eight spheres would best represent the Earth, Sun and Moon, on the same scale and write their choice in the back of their books. The objects were laid out on a table at the side of the room for the children to access. Only one child went to the table for a closer look. The four smallest spheres (two different sized beads, peppercorns and cake decoration balls) were passed around the classroom in small lids.

On completion of the task, a census was taken as to who thought which sphere represented which object. The beach ball, the largest sphere, was generally selected as the Sun, though some of the children had selected the next largest sphere (a football) as the Sun. After collating several of the children's answers, 'beach ball for Sun' was written on the board. There was then confusion about the relative sizes in the selections for the Earth. Some children, who had selected the beach ball for the Sun, then selected the football for the Earth and some, who had selected the football for the Sun selected the tennis ball for the Earth. Several of the children said they had selected the small blue bead as the scaled size for the Earth. This was written on the board. At this point several children wanted to change their mind about their selection for the Moon and were afforded this opportunity.

The spheres that were designated by the teacher as Earth, Sun and Moon were held next to each other, by three children, at the front of the class. This enabled all the children to see the differences in size, with the teacher reiterating the distances, but not showing them, or re-iterating the fact that there is empty space between the three objects. The accompanying talk and gestures did not add any extra information to the demonstration other than to reinforce the names and relative sizes of the Earth, Sun and Moon. Again, analysis shows that only structures, the naming of the objects and their relative dimensions, were made available to the children.

This activity was followed by an introduction to a new topic, day and night. The teacher picked up a geographical globe from the side of the room. A child was selected to give their ideas about the reasons for day and night, (this child was one of the interview group). The geographic globe was used by the teacher to demonstrate what the child was explaining.

Whilst the teacher was turning the globe clockwise the children were able to see one rotation period of the globe. This period was re-stated, by this movement as one year, the statement made by the child, but the teacher then asked for any other ideas, indicating that this idea might not be right. The next child selected answered 24 hours, but when asked to elaborate on their answer stumbled in replying.

The teacher had noticed the obvious confusion shown by two of the children and as stated in the teacher interview, stopped and retraced the information. The fact that the Earth is spherical was reinforced by reference to it as a ball. The rotation of the Earth was shown as a clockwise turning of the globe, (at the same time as the verbalisation) and the orbital path of the Earth was described with a large arm movement as a clockwise circle in front of the globe.

At this point the teacher picked up the beach ball, which the class had agreed represented the Sun in the previous activity scaling the relative sizes of the Earth, Sun and Moon. A child was selected to be the Sun, holding the beach ball, and positioned to one side of the room. The teacher then indicated by drawing a horizontal clockwise circle in the air, the path that the Earth takes as it goes around the Sun. At the same time as spinning the globe slowly in a clockwise direction the teacher said "the Earth spins on its axis once every 24 hours, which is what we call a day".

In every instance that the teacher rotated the globe it was in a clockwise direction. Whether the children understood this as clockwise or viewed the movement as anticlockwise from their perspective was not clear. The teacher did not specify the direction of the rotation of the Earth at this point.

The teacher then moved around the child who was representing the Sun, walking in an off-centre, clockwise, elliptical orbit, with the globe held at chest height. The shape of the orbit was mainly due to the space constraints at the front of the lab, but was open to interpretation by the children as an off-centre orbit. The teacher did not specify the direction or position of the orbit of the Earth around the Sun, but implied a clockwise orbit as this was the direction taken. Previously the orbit had been described as elliptical rather than circular (Lesson 4). The demonstration was then repeated, using just the globe and hand movements, but the teacher reinforced the time periods.

The teacher proceeded to demonstrate day and night using the 'Sun' and the globe. Indicating a point on the globe, about the equator, the direction and pathway of the Sun's light was indicated by pointing backwards and forwards between the 'Sun' and the globe. The teacher used the same point on the surface of the globe, which was now rotated 180°, at the same time as saying "12 hours later", reinforcing that facing the Sun, it was daytime and facing away from the Sun it was night time.

The demonstration was analysed using the Buckley and Boulter grid (Table 5.13). Though the mechanism for the occurrence of night and day was made specific, the direction of the orbit and rotation of the Earth was open to confusion. No light source was actually used, though the child holding the beach ball, which was made with six differently coloured panels, did orient the yellow panel towards the Earth, therefore showing knowledge of a conventional representation of the colour of the Sun and its light, but this was a spontaneous action and not suggested or requested by the teacher.

Structure	Behaviour	Mechanism
Large sphere (Sun – beach ball). Smaller sphere (Earth – globe). Light from Sun (hand gesture). Position on globe identified.	Globe rotated clockwise – 'turns once every 24hrs' (talk). Light travels directly from Sun to Earth – (hand gesture). Globe moved around Sun – clockwise.	In 'sunlight'/not in 'sunlight' due to rotation of Earth.

Table 5.13 Analysis of day and night demonstration – Buckley and Boulter.

The mechanism of the rotating Earth causing day and night to occur was reinforced through the use of the representation. This is the first instance of a representation providing behaviours and mechanisms.

5.5.7 Lesson 8

In the next lesson the children drew a diagram of day and night in their books. The teacher drew on the board describing each part of the diagram as it was added. This acted as a reminder to the children of the demonstration in the previous lesson and showed how the parts of the diagram were related to each other. The diagram on the board was a copy of page 95 from the CGP book (Parsons 1999) (Figure 5.6), without the colours or shading, therefore removing the clues as to the spherical nature of the Earth.

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Figure 5.6 Representing day and night – page 95 CGP (Parsons 1999).

The diagram from the book was analysed using the Goldsmith (1984) grid to assess what information was available in the diagram (Table 5.14).

	Syntactic	Semantic	Pragmatic
Unity	Part circle Circle Thick and thin dotted red lines Outlines on circle Arrow	Yellow colour for part circle Green land masses on blue circle	
Location			Context enables white arrow to be rotation
Emphasis	Colours of Sun and Earth Grades of colour	North and South poles	Green land masses
Text parallels	Sun, Earth, light rays labelled		

Table 5.14 Analysis of page 95 CGP book (Parsons 1999) – Goldsmith.

There are several layers of information absent from the diagram. The Earth is not accurately located in relation to the Sun, which is not named. There are no scale clues, in fact the size of the 'Sun' and Earth are similar. The children were not given access to this diagram; it was used as an 'aide memoir' for the teacher as the diagram was constructed on the board.

If the diagram is then analysed using the Buckley and Boulter (2000) grid, the layers of information that are absent are seen to be in the behaviours and mechanisms operative in the process of day and night (Table 5.15).

Structure	Behaviour	Mechanism
Part circle for Sun Circle for Earth Arrow on Earth Yellow colour – sunlight Black – absence of light	Arrow indicating movement	

Table 5.15 Analysis of page 95 CGP book (Parsons 1999) – Buckley and Boulter.

The diagram on the board lacked any colour definition, but the teacher added labels, both written and oral. The lack of scale clues in the diagram was dealt with by the teacher explaining that the Sun was many times bigger than the Earth.

The axis was described as it was added to the diagram and labelled on the board. Its function was explained as it was drawn. The arrow indicating rotation was not labelled on the board but its function was explained as it was drawn. The arrow indicates an anticlockwise rotation around the North Pole and this was reinforced by the teacher using their hand to draw a horizontal, anticlockwise circle in front of the board. This was not the direction of rotation indicated by the teacher in the previous lesson, whilst using the geographical globe. The teacher noticed that one child had placed their arrow inappropriately in their book and the teacher reinforced the idea that the Earth rotates anticlockwise on its axis by placing the globe in front of the Earth circle on the board and rotating it anticlockwise.

By questioning the children, the side of the Earth in daytime was established and labelled on the board. The teacher added some of the information missing from the diagram in the book, using gestures and oral explanations. This was done during the construction of the diagram and gave the children information that would not appear on the diagram in their books. The construction of the diagram was analysed using the Buckley and Boulter (2000) grid (Table 5.16).

Structure	Behaviour	Mechanism
Arc for Sun Circle Three lines with arrows from Earth to Sun	Arrow denoting direction movement – of Earth and sunlight – also shown with gestures	Shading on half of Earth – denoting night time Talk – facing away from the Sun

Table 5.16 Analysis of board diagram – Buckley and Boulter.

The children all copied the diagram as it was constructed by the teacher on the board. Figure 5.7 shows an example of the finished diagram in one of the children's books.

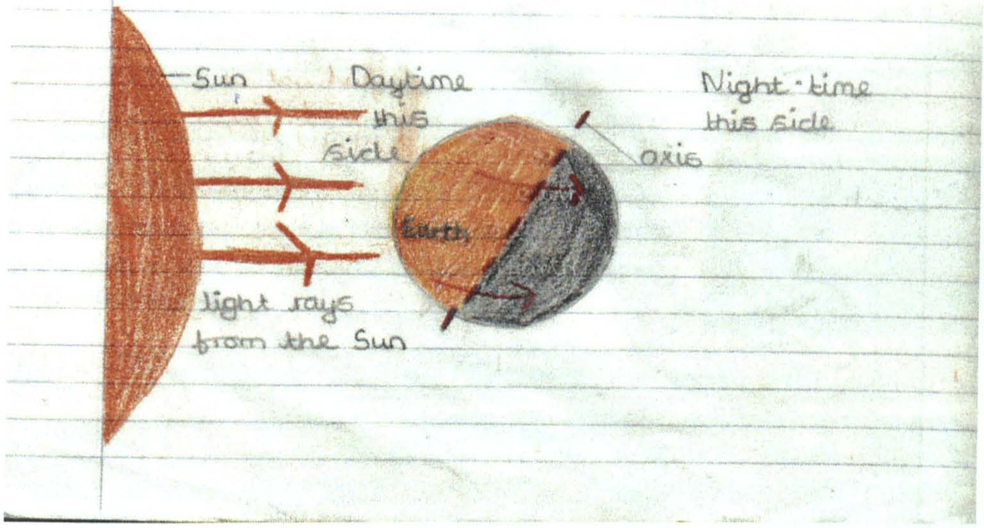

Figure 5.7 Day and night diagram in an exercise book.

Once all the children had finished copying the work on the board, the teacher introduced the next topic.

The children were given the CGP book and asked to look at the diagram on page 96 depicting the reasons for seasons (Figure 5.8). The teacher was very aware of the common misunderstanding of the proximity of the Earth to the Sun causing increased heat experienced in summer in temperate climates. The teacher drew the children's attention to the demonstration they had seen in a previous lesson with the different sized spheres, pointing out the differences in distances and size of the Sun and the Earth. Using the diagram, which the children had in front of them and which the teacher was holding at the front of the class, each aspect of the diagram was pointed out.

The teacher indicated the areas of the page by pointing. When talking about the intensity of the sunlight, a flat palm hand gesture pushing towards the Earth's surface in the diagram was used. This had the effect of indicating the importance of the direction of the sunlight and indicating how the light hits the Earth's surface.

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Image redacted due to third party rights or other legal issues

[redacted]

Figure 5.8 The seasons – page 96 CGP book (Parsons 1999).

The illustration does not show the mechanism that causes the light and temperature variations of seasonal change. The teacher emphasised the tilt with gestures and talk about the Sun's energy, but this is not indicated in the diagram.

The teacher acknowledged to the children that this was a difficult topic and asked them to read the book and 'get to grips' with it, so that they could follow up the points of the lesson after the half term holiday (a week) between lesson 8 and 9.

5.5.8 Lesson 9

The teacher introduced the lesson with a recap of the previous lessons covering day and night and the period of a day and a year, using the globe. Nothing was added to the previous demonstrations of these topics, therefore this served as re-iteration for the children.

The topic of seasons was introduced by reminding the children of the session at the end of the previous lesson which took place in lesson 8 before the half term holiday. The teacher selected a child to hold the beach ball and holding the globe, reiterated the tilt of the Earth. The tilt was indicated by both the globe and the teacher leaning slightly (globe and teacher to the right). The rotation was reiterated with the teacher turning the globe clockwise. The period of a year is indicated as a clockwise ellipse around the Sun, drawn with extended forearm and finger, in the air, four times. The hemispheres were indicated by pointing, and the equator, marked on the globe, pointed out. The teacher, holding the globe, moved clockwise around the child holding the beach ball.

The teacher shuffled around the child in a clockwise direction, pausing half way round, to ask questions and then continuing around. By stating that the positions stopped in were six months apart the teacher reinforced the notion of the Earth's orbital period being twelve months.

The period of orbit is further reinforced when the orbital path of the Earth around the Sun is described in terms of the teacher's movement and the description of the seasons that occur during the yearly orbit.

The teacher again reinforced verbally that the distances involved were huge and showed the children a comparison with the small blue bead, identified in lesson 7 as representing the Earth on the same scale as the beach ball Sun. The blue bead Earth was held by the teacher at one end of the lab and the beach ball Sun was held by a child at the other end of the lab. The teacher tilted the blue bead slightly to show the children that the slight tilt on the Earth became relatively insignificant, in terms of placing the Earth nearer to the Sun, due to the huge size differential of the two bodies and the vast distance between them. This was to indicate that the seasons could not be hotter because the Earth was closer to the Sun, and that there might be other factors involved

Analysis of this demonstration reveals that the mechanism that causes the seasons was not made clear. (Table 5.17)

Structure	Behaviour	Mechanism
Sphere – large small Distance Tilt (talk)	Flatter rays (talk) – gesture (hand and body) More spread out (talk)	

Table 5.17 Analysis of size and distance demonstration in relation to the seasons – Buckley and Boulter.

Once this demonstration was completed, the teacher used the Spectrum book (Cooke and Martin 2004) diagram (Figure 5.9) showing the reason for seasons and copied it onto the board for the children to copy into their books, (Figure 5.10). Once they had all completed this, a passage of text with missing words was written on the board for them to copy and fill in the gaps. As the children began to finish this activity a chart of temperatures in a number of different cities was handed out. The teacher explained that next lesson they would draw graphs from these charts and then they would be able to tell which city was in which hemisphere and which season it was in that place.

Image redacted due to third party rights or other legal issues

[redacted]

Figure 5.9 The seasons – page 152 Spectrum 7 (Cooke and Martin 2004).

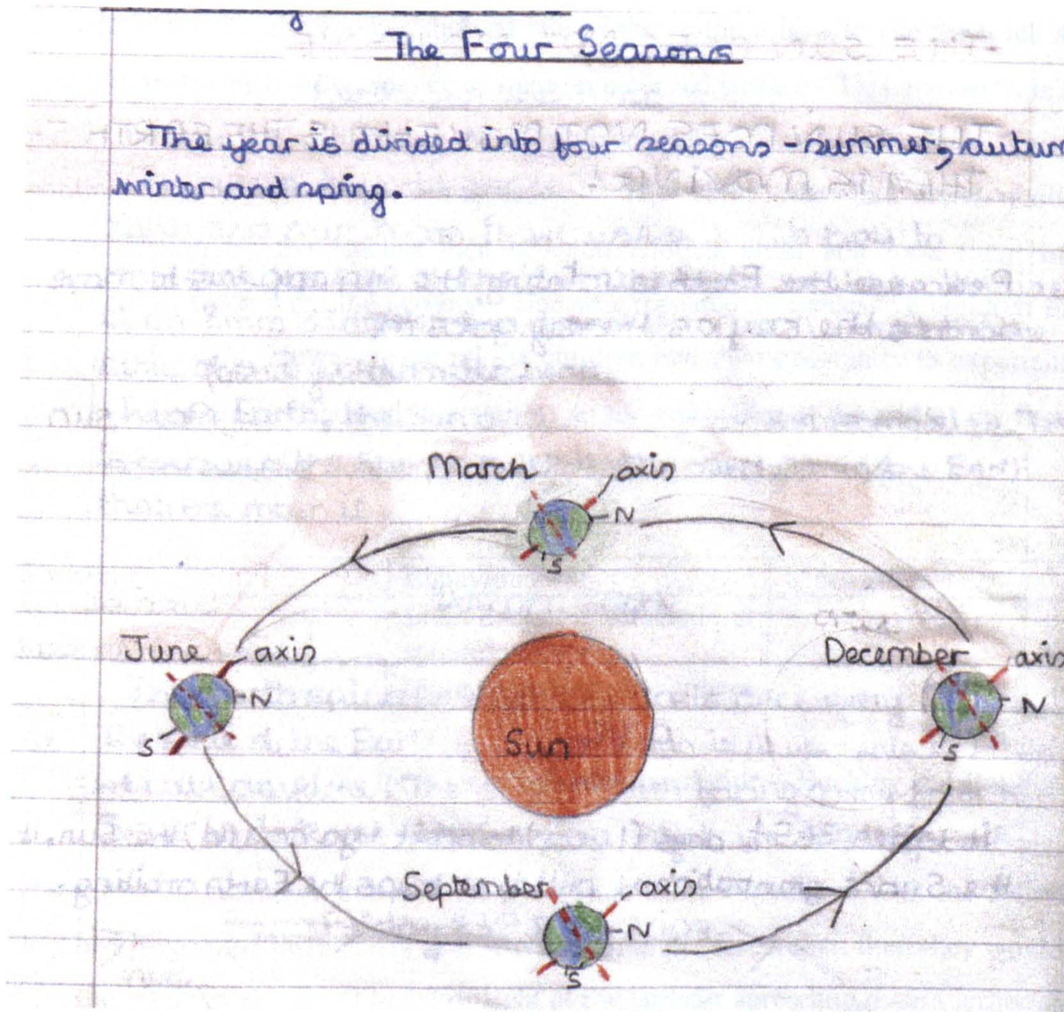

Figure 5.10 The seasons diagram in an exercise book.

5.5.9 Lessons 10 and 11

The worksheet introduced at the end of lesson nine was an exercise in bar graph construction. The aim was to identify where on the globe each of three cities was situated by virtue of graphs of temperature changes throughout the year. This was not elaborated and the questions were not discussed; therefore the activity equated to a comprehension exercise. Because the questions were not discussed, it was not clear whether any of the children drew any conclusions about the different temperatures in the different cities. No writing accompanied the graphs in the children's books. The temperature differences represented a mechanism operative in seasonal difference, as the temperatures recorded differences at the same time of year. This was not explained to the children, who were expected to draw their own conclusions from the information they had translated into graphs and from the questions they answered from the board.

During lesson 11, the teacher showed one of the children how to use the torch and the globe to investigate the incidence of light on a curved surface. This activity was carried out in the store cupboard, being the only place where it was totally dark. This was a continuation of the lesson on seasons. The child who had been shown the demonstration by the teacher then selected another child and took them into the cupboard to show them the activity. This was repeated as successive children finished their graph work. However, not all the children had the opportunity to experience this activity. The teacher showed this activity to the researcher at the end of the lesson. It was analysed using the Boulter and Buckley (2000) grid (Table 5.18).

Structure	Behaviour	Mechanism
Sphere Light source	Light source directed at sphere Light spreading over sphere	

Table 5.18 Analysis of the incident of light demonstration – Buckley and Boulter.

There was no guarantee that each child had the same experience with the activity. If they had performed the activity as it was shown to the researcher, then they would have seen the effect of the direct beam of light at the equator spreading over a larger area on the increasingly tangential surface of the globe as demonstrated Figure 5.11. Factors of distance were not included in the activity, and were in fact ignored, as in order to get the torch to produce the required effect it had to be held very close to the globe.

Image redacted due to third party rights or other legal issues

Figure 5.11 Demonstration of light intensity.

5.5.10 Lesson 12

The globe and torch activity was repeated for the whole class, with the teacher standing at the front and holding both objects. It was not very effective as there were no black out facilities in the lab. The fluorescent strip lights were turned off but there was still light from the windows (on two sides) which was reflected off the shiny surface of the globe in addition to the light from the torch, so the area of the globe illuminated by the torch, though held close enough to be distinct may not have been obvious to all the class. The teacher drew the children's attention to the central part of the light beam, which was shining on the equatorial region and told them these were direct rays, but further up the Earth, the rays were slanted and not direct. The teacher reminded the children of the activity with the tilted blue bead and the beach ball Sun, suggesting that it was the Sun's energy striking the tilted Earth rather than the proximity of the Earth to the Sun that was causal in seasonal change.

The main topic for this lesson was the phases of the Moon. The teacher introduced the topic which had been discussed briefly at the beginning of the previous lesson. The representations used were a diagram on the board and a worksheet. The board diagram was based on page 94 of the CGP book (Parsons 1999) (Figure 5.12) which the teacher used for reference whilst reconstructing it on the board. As each item was added to the diagram questions were asked.

Image redacted due to third party rights or other legal issues

[redacted]

Figure 5.12 The phases of the Moon diagram page 94 CGP (Parsons 1999).

The teacher altered the diagram as it was constructed on the board, so that it was slightly different from the book diagram, putting the Moon slightly below the position shown on the book diagram. As the four positions of the Moon were drawn in, the children were asked which part of the Moon the Sun was shining on and what we would see from Earth. A Goldsmith analysis of the book diagram allows the information available to be assessed (Table 5.19).

	Syntactic	Semantic	Pragmatic
Unity	Circles Part circle		Landmasses and oceans
Location			
Emphasis	Colours, Sun yellow, Earth blue and green		Yellow – sunlight Blue and green Earth
Text Parallels	We can see sunlit side of Moon from Earth	Names of full and half Moon	

Table 5.19 Analysis of phases of the Moon diagram CGP pg 94 (Parsons 1999) – Goldsmith.

There is limited information in the diagram. The text, which the children were given in the teacher's explanation, adds little to the pictorial representation. Further analysis using the Buckley and Boulter (2000) grid reveals that, though the mechanism is not obvious in the book diagram, the teacher's explanation as the diagram is constructed facilitates its recognition (Table 5.20).

Structure	Behaviour	Mechanism
Part circle Yellow arrows Large circle Smaller circles	Sun shining on the Moon and being reflected to Earth (talk and gesture) Orbiting Moon	

Table 5.20 Analysis of the phases of the Moon board diagram – Buckley and Boulter.

The board work was followed up by a worksheet (Figure 5.13) which the teacher presented to the children as a shape sorting exercise to be completed for homework. The shapes on the sheet included the partial phases of the Moon (crescents) which were not explained to the children.

Main 7L.3 Lights in space

Activity 7L.3c Phases of the Moon

Remember:

- The Moon reflects light from the Sun.
- On Earth, we can only see the part of the Moon that is in the Sun's light and facing the Earth.
- The shape of the Moon seems to change over a four-week period.
- These changing shapes are called the phases of the Moon.

Look at the pictures. They show the phases of the Moon. They are in the wrong order.

1 Cut out the pictures and put them in the correct order. (Hint: Start with A.)

Image redacted due to third party rights or other legal issues

2 Observe the Moon for a week (cloud permitting). Draw what it looks like each day. If you can, note what time it rises.

470 7L.3

Figure 5.13 Phases of the Moon worksheet – Spectrum 7 Teachers Book (Cooke and Martin 2004).

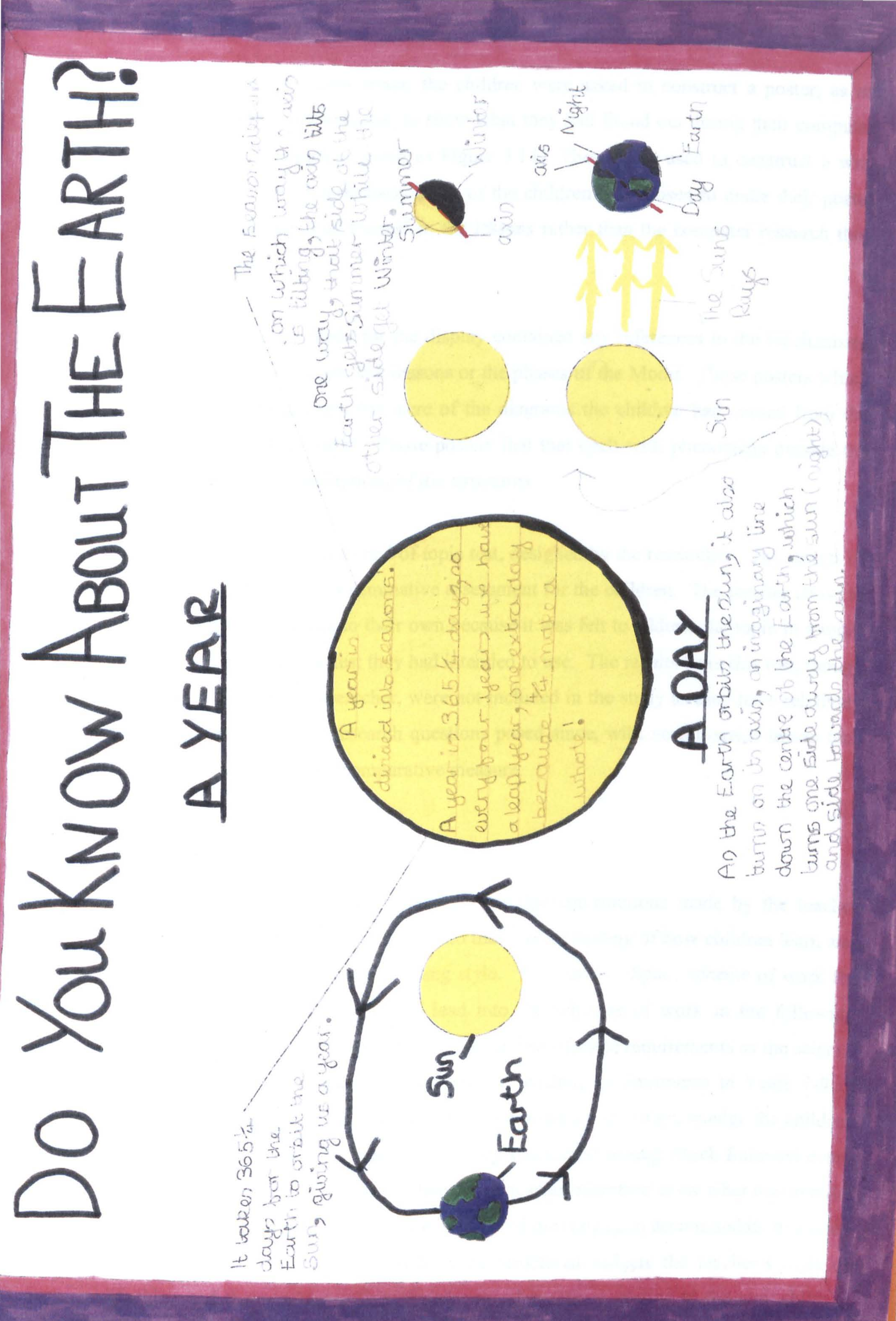

Figure 5.14 Example of a poster for the wall display

At the end of the lesson series, the children were asked to construct a poster, as an additional homework exercise, to show what they had found out during their computer research. An example is given as Figure 5.14. These were used to construct a wall display in the lab. Interestingly some of the children had chosen to make their poster about the facts they had learned in the lessons rather than the computer research they had completed.

None of the posters made for the display contained any references to the mechanisms involved in day and night, the seasons or the phases of the Moon. Those posters which did refer to these phenomena were of the diagrams the children had copied from the board and into their books. Those posters that that dealt with phenomena outside the Solar System were descriptions of the structures.

The children were given an end of topic test, designed by the researcher. The results of this test would be used as summative assessment for the children. The teacher chose to use the test in preference to their own because it was felt to address the topic in a more considered way then the test they had intended to use. The results from this test, though made available to the researcher, were not included in the study as they have relatively little significance to the research questions posed since, with no pre-series lesson test, there was no facility for a comparative measure.

5.6 The teacher

The observation of the series of lessons and the contributions made by the teacher during the interview, gave an insight into their understanding of how children learn and their pedagogical practice and teaching style. The Earth in Space scheme of work for the Year 5 group was designed to lead into the schemes of work in the following academic years. The study teacher had an overview of these requirements as the science co-ordinator for junior and infant houses and teaching commitments in Years 7-9 in senior house. There was, therefore, an assumption of a body of knowledge the children were required to have. This was supported by summative testing which followed every science topic and at the end of each term. The teacher therefore knew what information the children were required to have and structured the lessons to accommodate this body of knowledge. The way the lessons were structured reflects the teacher's style of teaching and their understanding of pedagogical practices relating to the way children learn and is seen in the video recording of the lessons. The teacher's views of teaching and learning are further evidenced by the responses in the teacher interview and to an extent by the methods employed in the classroom seen in the video recorded material. Excerpts from the interview and video recording are given below to illustrate these points. These factors relate to the representational material selected and the way it was introduced and used with the children.

The series of lessons addressed the Earth in Space topic in an order determined by the teacher which reflected the curriculum guidelines. Some of the aspects of the topic covered by were not required by the National Curriculum for Science, but the teacher included them as part of the topic, possibly because of their strong views about what the children should be or should not be taught. For example, referring to science topics in general:

> *"I cannot stand telling the children things that are incorrect in order to make things simpler for them .... I would rather say to them, 'This is what you need to know, I'm not going to tell you any more, because it's too,.....difficult, you don't need to know at this stage, but I'm not going to tell you what's wrong'." (Teacher interview 109-111)*

The teacher was aware of the requirements of the science curriculum from Key Stage 1 to Key Stage 3 and regarded the seasons and the phases of the Moon as part of the knowledge children should have at Year 5 level, even though they are no longer required by the current curriculum:

> *"That's the way I prefer to do it, 'cos having talked about a year, it's that, you see, that's the first stage and then looking at what the effect of that is."* (Teacher interview 186)

The science teaching for Year 5 was shared between two teachers and the teacher had views about the level of scientific understanding required by colleagues to teach science. The teacher acknowledge that teaching science was potentially difficult for some staff and felt that some scientific background knowledge was essential for anyone teaching science in order that they address the scientific concepts they were required to teach:

> *"I think it makes a huge difference (57)...... somebody like X for example, I have to teach them before they teach the {children}. I have to take them through everything step by step, before they can teach it to their class. Whereas, somebody whose science (...) has got a science background, knows the stuff already. I mean I don't have to learn the stuff before I teach it. I might have to refresh my memory, if I have not taught for however long, but I basically understand what's going on and how it all works."* (Teacher interview 61)

This was further discussed when referring to the children's learning. Again, the teacher reiterated the importance of scientific knowledge:

> *"This is my third year in teaching science at this level, and it's something that hit me straightaway, was how important it actually is and I don't think that people realise how important it is that the person teaching[......] science has to be absolutely confident in what they're doing and their knowledge, 'cos if you start leading them down the wrong path, 'cos you don't know what you're on about they're going to be, phut, forget it, they're going to be so confused."*
> (Teacher interview 92)

The teacher went on to discuss a teacher's limited scientific knowledge for children's potential learning. A passing reference was made to the children's mental models and possibility of misunderstandings, in the excerpt above which was qualified in terms that it was felt that teachers had to be 'absolutely confident' in their knowledge and understanding of the science to be taught:

> "I: *That you build on their misunderstandings?*
>
> T: *Yes, you've got to be able to say, hang on no, you know, stop, you're wrong. Let's go back a step and if you are a scientist then you can obviously do that, but if you're not, you're going to flap around just as much as they are.*
>
> I: *Would you necessarily spot where they have made mistakes?*
>
> T: *If you weren't a scientist, no I don't think you, [...] wouldn't have the deeper knowledge."* (Teacher interview 93 – 97)

The significance of science background knowledge was also cited by the teacher as having an impact on the materials that teachers use in their classrooms. Limited understanding of the scientific principles involved in a topic was seen by the teacher as affecting a teacher's ability to understand and therefore explain to the children the representational materials which had been selected for use in science lessons by the study teacher as science co-ordinator.

Referring to the Spectrum scheme (Cooke and Martin 2004) recently selected for use throughout the junior house:

> … *I liked it so much when I saw it that I immediately said we would have it. We'll have two class sets of books and a teacher's pack and the two CD-ROMs, which we haven't used yet, but we will do, because it's got lots of potential for homework activities and I just thought it was good really, very well produced, very well thought out.*
>
> (Teacher interview 5)

> *I think it's important with any science* [that a teacher teaching science should have a science background] *because I think you have to know much more than the children in order to be able to see a, where they are coming from in terms of their understanding and b, be confident enough to put them right.*
>
> (Teacher interview 86)

The teacher did monitor the children's contributions during lessons and occasionally gave them the opportunity to correct statements they made. In the first lesson of the series, where the children were guessing what the contents of the Solar System might be, one child was selected to answer:

"T: *Rosi!*

R: *Stars*

T: ***<u>In</u>*** *the Solar System? {Moves to the board and starts to write} Rosi wants me to write stars.*

M: *Planets*

T: *Well wait a minute we're with Rosi (indicating Rosi with their left hand) at the moment. Rosi wants me to write ………stars. There's one thing wrong with what I've written there. I cannot write starsssss (points to the s). Al why not?*

Al: *The Sun is a star*

T: *Are there any other stars?*

Al: *No*

T: *I can write star*

Rosi: *I said that*

T: *No, you said starsss*

Rosi: *mumbles*

T: *There is one star in the Solar System.*

Al: *The Sun*

T: *Good we'll have that as well, the Sun. Good we're getting there."*

The teacher picked up on Rosi's contribution of 'stars' and proceeded to challenge all the children to think why this might be an incorrect answer. Another child, Al, clearly knew the answer and supplied the correct version for the teacher. Therefore the idea that there was only one star, the Sun, in our Solar System was addressed.

In a later lesson, (lesson 8) the teacher referred to the common misunderstanding that seasons occur due to the Earth being closer to the Sun in the summer.

> *"T: Fine, OK, let's just make sure people understand it, because it's not easy. Now quite often when you ask people why we have the seasons, they say oh, it's because the Earth's nearer the Sun in the summer and we're further away from the Sun in the winter. What a load of rubbish!! Given the distances we're talking about, it makes not one jot of difference." (Lesson 8)*

The teacher was aware that this is a common misunderstanding. An earlier lesson (lesson 7) had comprised an activity of selecting three spheres from a selection of eight differing sizes to represent the Earth, Sun and Moon. Whilst making the above statement the children were looking at a page in a book (pg 96 CGP Parsons 1999 Figure 5.8) and the teacher was holding the same page at the front of the class whilst speaking. Whilst this statement was correct, in that it is a commonly held misunderstanding, there is an assumption that the selection of spheres to represent the Earth, Sun and Moon activity of the previous lesson (two days before) had been understood and accepted by the whole class. The activity was not repeated during this lesson. Therefore, whilst being aware of the possibility of misunderstandings, and understanding the importance of challenging misunderstandings (teacher interview 92 – 97 above), by making the statement at the beginning of the lesson, it effectively prohibited any discussion. In this instance the teacher was using representational material to give the children facts in an attempt to correct the misunderstandings it was presumed they may have.

The explanations given by the teacher often involved periods of questioning. The questions were direct and closed, leaving the children to guess what word the teacher was thinking of:

> *"T: Does anybody know what we call, what do we call it when something goes round something. It's a special word beginning with o. Oh look at the hands! This is good. Lou.*
>
> *Lou: Orbit*
>
> *T: Yes, well done, orbiting."* (Lesson 2)

This type of questioning seemed to work well for the children, who clearly enjoyed 'getting the right answer'. It also corresponded to the ethos of the school and therefore corresponded with the way other teachers would operate in their classrooms. It is a form of exchange of ideas about the topic and is non-threatening, unless the teacher chooses someone who does not know the answer. This rarely happened. In all of the lessons, the same children were repeatedly asked to supply answers to questions. These children were the ones who usually knew what reply the teacher was looking for, the 'right answer'. This enabled the children who did not know the required answer to appreciate what was required without having to admit they did not know. In this type of classroom environment not knowing the answer carries the stigma of ignorance. The children who were selected to answer questions appeared to have a wider knowledge base of this particular topic than the class generally. One of the children repeatedly selected to answer questions was part of the interview group. Their explanation of the reasons for seasons and the phases of the Moon, given in the interview prior to teaching the series of lessons, showed a reasonable understanding of the mechanisms involved.

The teacher was very efficient at recapping information at the beginning, end and occasionally, during the course of a lesson. This was a useful tactic for children who may struggle to follow the progress of the lesson, though it does not give any opportunity for children to challenge their ideas. Several attempts to ask questions were made (see second quote from lesson 4 below), but the teacher verbally and gesturally, holding a flat palm to the class, discouraged this:

"T: On Wednesday we had a sort of brainstorming session [pause for quiet – flat hand gesture] Thank you. We had a sort of brainstorming session to try and work out what sort of things were in the Solar System and we came up with lots and lots and lots of different ones. The ones we're going to concentrate on today are those planets" (Lesson 2)

"T: So we started,[flat hand gesture] just a minute let me finish my thing, we started talking about the Solar System and learning a little bit about the Solar System and we've made [...pause...] some little models of the distances the planets are from each other. [...pause...] So we've had a little think about how far the planets are from each other, so we've got those four, can anybody remember what those planets are called, err no we'll go back a bit. Who can remember the names of them? Who can remember the names of the first four planets? C ?

C: Rocky planets

T: They are the rocky planets. What are their names, [...pause...] in order?

(Lesson 4)

Having established the facts it was considered the children should know, the next phase of the lesson was introduced. If this was an activity, it was explained whilst the children sat and listened to the teacher talking at the front of the class. If it was copying from the board, the topic was introduced and the teacher began writing, the children copying as the work was written. Only very occasionally did the teacher read whilst writing, making it difficult for the children who wrote slowly to copy from the board, without the aural clues. Consequently, there was time allocated for them to finish off, once the teacher has completed the board writing. Writing on the board was a significant feature of the lessons and did not constitute the use of representational material for the purposes of this study. The notes on the board were for revision for their end of topic and termly summative tests. The teacher felt that it was important that all the children had the same notes and by writing them on the board was confident that all the children would have the same information neatly presented in their books. There are also implications embedded in neat, accurate presentation of work in books which involve colleagues, heads of school and parents, suggesting that the appearance of the children's work reflects the teacher's competency. Therefore this forms part of the teacher's style of teaching and informs the organisation of lessons which in turn determines the use made of representational material as presenting the facts that the children would subsequently record in their books.

5.7 The group of children

The group were self selected in that they were the four children who had done sufficiently well in the test for the topic previous to the Earth in Space to not warrant sitting through the recap and correction session of lesson one.

The group were asked by the researcher if they knew how the seasons worked. There were three pages from books and a concept cartoon to act as prompts during the interview (Figures 3.1, 3.2, 3.3, and 3.4).

The interviews were checked for any references made by the children with regard to the structure, behaviour and mechanisms of the seasons. As the second interview was considerably shorter the phases of the Moon had not been covered in as much depth as seasonal change. It was therefore decided by the researcher to cover only seasonal change in the analysis. The references to seasonal change were mainly about the children's personal experience of the seasons. This was to be expected, as the children had not begun the series of lessons. Figures in brackets refer to the lines of the interview transcript.

> *R: well there are four seasons, winter, spring, summer and autumn, and winter is a cold month and summer is hot and spring is when all the flowers start to come out, autumn's when the leaves start to die and wither.* (4)

Most of the references the children made were of this type, for example:

> *in summer there's more light (13)*
> *spring flowers coming out (41),*
> *in winter there is more rain (44),*
> *rain might block the Sun (62),*
> *foggy and misty in winter (67).*

These types of observations have been identified by previous researchers (see Chapter 2) as being typical of explanations about the seasons. The initial response is to identify the physical occurrences, changing weather, observable plant activity, animal behaviours and to name the seasons, without any reference to causality.

One child (J) brought into the discussion factors about the Earth's tilt and the proximity of the Earth and Sun affecting the changing temperatures:

J: When our side of the Earth is erm nearer the to the Sun you have summer and the other side have winter (26)

This was picked up and the idea taken further:

J: During the spring and autumn the Earth doesn't lean towards so much the Sun and in summer it leans more to the Sun (101)

J: 'Cos when the northern, when it's tilted the northern hemisphere goes like that (tilts their hand at 45°) towards the Sun where it is summer, when the southern hemisphere is tilted they get summer (109)

The angle of the suns rays was also referred to:

C: It depends on what slanting ray our thing is

I: So you're saying that on days when the rays are really slanty what sort of weather?

C: It will probably be quite cold.

I: Why?

C: Because the Sun doesn't have a direct ray and the Sun gives heat (156 – 161)

C: So if you, if the North Pole is away from the direction of the Sun in, so the Sun spreads out and so they get a little bit of Sun during the summer, when they are slanted in the direction of the Sun' cos they get more Sun (349)

C: No, say the Sun's there (indicates a place away from themself) and the Earth is like that (holds hand near to themself, shaped as a fist), it is round the, erm, if you look at the circle it would be slanting up to the North Pole and we would be about here (indicates a point near the top of their fist) the equator is right nearest the Sun that's why it gets more heat (442)

Applying the Buckley and Boulter (2000) analysis grid shows that the children refer repeatedly to the structural aspects of the reasons for seasons, *slanty rays, direct rays, sun gives heat, slanting circles, nearest the Sun,* but the behaviour of these elements is only briefly referred to by child (J) who has a notion that the tilt of the Earth is implicated in the changing temperatures but is unable to clarify that it is not the variation in the distance to the Sun that causes temperature change.

In the second interview, after the series of lessons, the children are quite clear that the tilt of the Earth's axis and slanting rays from the Sun are the reason for seasons (figures in brackets refer to interview transcript line number):

This has direct rays (22)
And slanting rays (23)
The seasons are to do with the axis and how it tilts (156)
The axis you should know about the axis for the seasons (182)

They do not refer to the mechanism of the changing heat and light due to the slanting or direct rays, or the effect of the curved surface of the Earth on the angle of incidence of the Sun's energy.

The children again referred to the structures of the reasons for seasons and the phases of the Moon with only a brief mention of the tilted axis affecting the seasons. The way they referred to the tilt could be classified as a structural reference by the majority of the group. Child J mentioned the tilt and the angle of the Sun and direct and slanting rays. These are structural aspects of the causal mechanisms of seasonal change. A count was made of the structural, behavioural and mechanistic references before and after teaching (Table 5.21).

	Pre-teaching	Post-teaching
Structure	38	0
Behaviour	82	27
Mechanism	0	0

Table 5.21 Pre- and post-teaching references.

The initial interview was considerably longer than the second interview, with consequently more time for the children to express their views. The children were more focused on the structural aspects in the initial interview, which were not mentioned at all in the second interview. In neither case were any references to the mechanism which caused the seasons mentioned.

Interestingly in the second interview, the children became very interested in the type of representation in the pictures and discussed the relative merits of the pages from the book in detail. In the first interview, they made no comment on the structure of the pages, but in the second interview they volunteered comments about the contents and layout of the pages rather than reading them for information as they had in the first interview. As the focus of the research had not been discussed to the level of detail of the analysis of representations with the children, it was very surprising that they decided to give me their opinions on the layout and general structure of the pages. Though their comments were interesting and revealing, they cannot be included in the results of this study, but will be referred to in the discussion chapter.

5.8 Summary

The series of lessons in the study school showed a progression from the objects in the Solar System, through a study of the planets and their relative sizes and distances apart, to phenomena involving the Earth, Sun and Moon, the occurrence of day and night, the seasons and the phases of the Moon. Following such a progression allows opportunity for orientation of the Earth, Sun and Moon within the context of the whole Solar System. Whilst such a progression seems at first sight to be logical and coherent, there are a number of conceptual gaps which could have implications for learning and retention of knowledge gained during the series of lessons. This could have potentially been addressed by the use of representations, though it would have required a high degree of interpretation on behalf of the teacher and a greater range of representations, capable of bridging the gaps. The amount of use made of representations to illustrate the lessons indicates that the study teacher felt they were important aids to learning, in that eight of the twelve lessons contained some use of representations. The actual nature of the representations, their content and ease of interpretation had been assessed by the teacher and influenced the choices made. The materials had been chosen by the teacher with the stated intention that they were thought suitable for the lessons and the children in the class, a process common to all teachers. The fact that the analysis revealed missing areas of information was not known by the teacher.

There are several features that have been identified as being pertinent to answering the research questions posed for this study. These areas highlight problems of using representations with children, particularly when the children are required to make notes in their books. In the case of the study school these notes were to be used for revision for end of topic tests, and the teacher was adamant that all the children had the same notes to revise from. That the children did not have all the same notes in their books, despite having copied them off the board, is worth noting. The teacher marked the children's books correcting obvious errors and appeared to be satisfied that all the children then had the same notes.

The analyses of the representational material may indicate areas where the children's misunderstandings were not adequately challenged, enabling revision and/or reconstruction of their mental model. The way the representational material was introduced to and subsequently used with the children may also have contributed to their construction of knowledge of the phenomena being illustrated by the materials. The differences in the diagrams copied from the board into exercise books might be a reflection of the representational materials used, in addition to the board diagrams, in that the majority of the representational material presented the children with only structural aspects of the phenomena. The conclusions drawn from the results presented in this chapter will be discussed in the following chapter with specific reference to the issues highlighted in the research questions.

Chapter 6

Conclusions

6.1 Introduction

The previous chapter presented the results of the analysis of the use and nature of the representational material in a series of lessons on the Earth in Space together with the results from the teacher and children's interviews. This chapter addresses conclusions drawn from these results to answer the research questions. Therefore the discussion will follow the pattern of the research questions. The overall findings are given in a summary.

The general research questions posed for this study were:

1) What type of representations do primary science teachers select?

2) How are these representations used in science lessons?

3) Do representational materials present a cognitively coherent pathway to facilitate the construction of knowledge by the pupils?

These general questions were made specific to the case in the study school and the following specific questions were posed

1a) What types of representation were selected by the teacher?

1b) What criteria were used for selection?

2a) How were representations introduced to the class?

2b) How much use was made of representations?

2c) Were representations used in combination?

2d) Were representations used in context?

2e) Were the representations 'fit for purpose' with appropriate informational content?

2f) Were the same representations used repeatedly?

2g) Were the same representations used for different targets?

3a) What was the teacher's understanding of the way learning takes place?

3b) Was the teacher aware of any potential misunderstandings the children might hold about the topic?

3c) Did the use of representations address the commonly held misunderstandings of the topic?

3d) Was the informational content of the representations sufficient for engendering knowledge construction and conceptual change in understanding?

The general questions will be used to indicate the section headings. The specific questions will be discussed under the general headings.

6.2 Selecting the representations

The first general question posed involves the actual representations selected by the teacher and the reasons for selection. The video recorded material showed the types of representations actually used by the teacher and therefore selected, the teacher interview conducted after the series of lessons gave evidence for the reasons for the particular selections.

6.2.1 Representations selected by the teacher

The most frequently used form of representation was the construction of diagrams on the board. This would accord with the requirement for the children to have notes for revision purposes in their exercise books as stated by the teacher in the interview and required by the summative testing at the end of each topic and term. Of the other types of representations, demonstrations of aspects of the bodies in the Solar System were the next most common. These had mainly been taken from a published scheme (Spectrum, Cooke and Martin 2004). The other mode of representation, the everyday physical objects to show the relative sizes of the Earth, Sun and Moon, was also chosen by the teacher because it was considered to show the differential in sizes of the bodies appropriately. This demonstration had been taken from the QCA (DfES/QCA 2005) scheme of work (5e) and had been used in previous years. The demonstrations also included the use of a geographical globe to represent the Earth.

The worksheets used for the order of the planets and the phases of the moon appeared in the teacher's book from the Spectrum published scheme Cooke and Martin (2004).

The teacher therefore chose four types of representation:

- diagrams drawn on the board – from text books
- concrete models constructed by the children
- physical objects for demonstrations
- worksheets.

6.2.2 Criteria for selection

The teacher had definite views about the type of representation to use in the classroom. The pictures and diagrams in textbooks were considered in terms of their informational content and physical construction; it was felt that they should contain enough but not too much information and this should be accurate. The diagrams copied from textbooks onto the board were thought to be adequate because they were presented in a published primary science scheme – Spectrum (Cooke and Martin 2004) and a revision textbook, Key Stage 2 Science (CPG) (Parsons 1999). The diagrams were representational material, though not necessarily regarded as such by the teacher, and were for the children to record information in their exercise books for future reference, with the intention that they all had the same information recorded. The teacher's statement that diagrams should not be cluttered or contain too much information meant that the teacher changed these diagrams as they were copied. The elements removed were therefore considered to be extraneous for the children or perhaps caused the diagram to be too cluttered. All indications of dimensionality and colour were removed as they were drawn.

The physical models chosen for construction by the children were considered by the teacher to be a good way of showing the particular facts about the relative distances between the planets and their relative sizes, despite the difficulties encountered by the children with their construction. These models had been taken from Spectrum (Cooke and Martin 2004). The teacher felt that because someone else had thought them through they were adequate for their purpose and therefore these had been carefully and deliberately chosen by the teacher as fulfilling their purpose.

As the scheme was new to the school there had been no opportunity to test the materials with children. The teacher did say they would be used again next year because they felt they were adequate, interesting and useful. The construction of these models did however take a large amount of lesson time, which the teacher did not refer to in the interview.

Therefore the types of representation selected by the teacher were:

- board diagrams
- models using everyday objects (balls, globe and torch) – as demonstrations
- models constructed by the children
- worksheets
- illustrations on a poster and in textbooks.

The criteria for selection identified from the analysis of the teacher interview and presented in the results chapter were:

- for diagrams and illustrations –

    clear

    unambiguous

    uncluttered

    appropriately coloured

    engaging for the children

- for models –

    clearly demonstrate a particular aspect.

The teacher therefore consciously selected the representations to use with the children using criteria they regarded as important. This is supported by Gates (2004) who suggested that teachers select material which is bright, simple and accessible. The way they were introduced to the children and their consequent use was noted from the video recordings.

6.3 Using the representations in the science classroom

The second general question was posed to investigate the way the representations were introduced to the class and actually used in the lessons. The teacher used some form of representational material in almost every lesson, though the amount of use was not consistent through all of the lessons. This is to be expected in any science topic and is dependent on the particular aspects planned by the teacher for illustration. The lessons when the children were constructing graphs from lists of data and conducting computer research were periods when they were working on their own or in pairs and the teacher did not interact with the material or the children other than to assist with technical and practical difficulties.

6.3.1 Introducing the representations

The general organisation of the lessons, shown by the allocation of categories in Table 5.2, shows that the teacher took time to orientate the children to the objective of the lesson. Once the objective had been introduced an explanation followed. Occasionally explanations involved the use of closed questions directed at particular children. In the case of the two models for the relative distances between the planets (string model) and the relative sizes of the planets (fan model) the intention of the model was given to the children. Therefore, the teacher was creating a model of someone else's ideas to reinforce the objective of the lessons – relative sizes or relative distances between and of the planets and the Sun. Though the intention of the models was given to the children the explanations were about their physical construction rather than any aspects of the models.

This was also the case for the diagrams constructed on the board. The board diagrams were generally constructed after a period of explanation or demonstration and were intended to serve as notes for future reference. The diagrams were usually built up line by line with some teacher explanation or gesture of what the lines represented being included as they were added to the diagram. This enabled the children to understand what they were adding into their drawing. Some information and gestures in these explanations were not included in the diagram. The material selected for re-construction on the board was simplified from the original diagrams as the teacher copied it. This involved removing colour, shading and any arrows, lines and written information considered by the teacher to be extraneous. This was a deliberate act on the part of the teacher and supported their views about the construction and content of diagrams. The children did not have access to the books from which the diagrams were copied.

Physical objects were introduced in a way which allowed the teacher to talk about the properties of the objects in analogous terms. This presupposes that the children were able to think in terms of analogies. One child in particular understood the analogous nature of the beach ball representing the Sun, when they turned the yellow panel of the ball to face the 'Earth' to indicate sun shine during the demonstration of day and night. It is possible that all the children were able to think in analogous terms, though whether the analogies that were intended by the teacher were understood in the same way by the children is not clear as there was little opportunity for the children to show their understanding.

The only physical object that consistently retained the same analogous characteristics was the beach ball 'Sun'. The Earth and Moon were represented at different times in different demonstrations as different sized spheres. The demonstrations were of different behaviours of the Earth, Sun and Moon and therefore the scale effect of using different sizes of spheres could be justified in terms of the different properties that were required to be shown for that particular demonstration.

Again this presupposes that the children understand analogous references and are also able to transfer their thinking about one set of analogous criteria to another physical object. The physical objects were drawn as circles in the diagrams on the board. There was no question that the teacher thought that this task was too difficult for the children to accomplish. Any children who were slow to copy were given time to finish their copying. The reason for their slow completion of the drawing tasks was deemed to be as a result of competence issues rather than lack of understanding of the required task.

Therefore the representational material was generally introduced to the children:

- after an explanation of the phenomena being studied
- and included description of the parts of the representational material
- and included references to scale where appropriate

- and made use of analogies.

6.3.2 Time spent using representations in the lessons

The amount of time spent using representational material varied from lesson to lesson. (Table 5.5 in the previous chapter). The most frequent activity was the time the children spent working on their own, cumulatively 35% of all lesson time. The lesson time in which the children and teacher were engaged in the use of representations compared with the times engaged in other categories of activities shows that representational use was the second most frequent activity engaged in the classroom, cumulatively a total of 19%.

The figure for the total use of representational material is skewed because of the four lessons not involving any use of representational materials, where the children were completing computer research and constructing graphs. If these lessons are removed from the calculations the proportion of time spent using representations during the lessons rises to 28%. There is no other research which details the use of representational materials as a proportion of lesson time, so a comparison with other lessons using representational material is not possible.

6.3.3 Combining representations

The first use made of physical objects was in Lesson 7 when the children were challenged to select three spheres from a group of eight different sized spheres to represent the Earth, Sun and Moon on the same scale. Once the decision had been agreed, the Sun was the only sphere consistently used to represent the Sun. The Earth sphere, a small blue bead, was used on one other occasion to represent the Earth in a demonstration of the impact of its tilt on the distance from the Sun in an explanation of seasonal change.

On other occasions when the Earth was included in a demonstration it was represented by a geographical globe, whilst the Sun remained as the beach ball. No explanation of the change in object was given to the children.

Physical objects, in the form of the beach ball 'Sun' and geographical globe 'Earth' were used to illustrate different phenomena. The use of different spheres to represent the same object is potentially confusing, though in the case of the Earth, the use of a geographical globe is probably a self explanatory representation.

The diagrams were diagrammatic interpretations of the demonstrations using physical objects. So in that sense the two types of representation could be said to be combined. The diagrams were intended to depict the activities which had been demonstrated and act as a record for the children. Whilst the diagrams were being constructed the teacher sometimes used gestures in addition to a verbal explanation of the lines being drawn. Analysis shows that these gestures added information to both the diagram and the explanation but this information was not always included in the diagram drawn by the either the teacher or the children.

Analyses of the demonstrations and board diagrams show differences in the informational content of these two instances of representation. The diagrams on the board lacked indication of movement, dimensionality or scale, aspects which were added during demonstrations, so the combination of the representational material presented different information.

Therefore, instances of the use of representational materials were combined with:

- explanations
- gestures
- physical objects
- diagrams.

6.3.4 Contextual relevance

When representational material was used it generally followed or was combined with an explanation. In most instances, therefore, the use of representations was in the context of the moment of its use. In lessons 8, 9 and 12 more than one topic was introduced. The changes in topic were preceded by an introduction, therefore giving a context to the new instance of representational use, but the same representational material was used.

Though the representational activity was introduced, and therefore given a context, it is possible that the change in topic was contextually confusing.

In lesson 9, the children were copying a diagram from the board which was to be a record of the demonstration in the previous lesson. This involved indicating where the Sun's light shone on the Earth during periods of day time. Once the work was finished a demonstration of seasonal change was introduced. This also involved the teacher talking about the Sun's light striking the Earth. This introduces contextual confusion, in that the globe 'Earth' and beach ball 'Sun' were used and light striking the Earth again described, but the events illustrated were different.

Though the majority of instances of representational use were in context, of both the explanation and the topic of the lesson, there were occasions, in three lessons in particular, where the use of representational material was potentially contextually confused as the topic emphasis changed but the representational material did not.

The contextual positioning of the representative material was also affected by the mode of representation. The main form of representation, diagrams, was generally preceded by either a demonstration or a verbal explanation by the teacher. The diagram therefore served as a permanent record of the demonstration or explanation, becoming a representation in its own right. For meaning to be constructed from the diagrams the children copied into their books, they would need to reflect the informational content of both the teacher diagram and the preceding explanation or demonstration.

A child's copy of a diagram Figure 5.7 indicates that the information has been changed again: the terminator line demarking daylight and night time is drawn in the wrong place. It follows the line of the Earth's axis rather than the perpendicular line of shadow caused by the Earth's curvature. It is possible that if the diagram had been completed in the same lesson as the demonstration, rather than in the following lesson with a recap explanation, the context would have been more relevant to the diagram.

- Therefore it would appear that though representational materials were generally used in context, there were occasions where they were not and this appears to have an effect on the meaning the children constructed from the materials.

6.3.5 Appropriateness of representational material

Representational material used in the context of the lesson objective was done so to facilitate construction of knowledge. This was stated by the teacher in their interview. The teacher also stated that they considered the material selected to be relevant, adequate and useful for the objectives of the lesson. The relevance and therefore appropriateness of the materials is dependent on the mode of representation and the context in which it is used. Board diagrams may not be the most appropriate representational material to use with this age group of children, due to the potential difficulties of 'reading' diagrams (Tversky 2000, Gates 2004).

Analyses of the board diagrams and the children's exercise books show that there were a number of changes made in the copying process. In order to understand diagrams, knowledge of the conventions used is needed (Tversky 2000). If the relationship between the parts of a diagram is not clearly understood the potential for the construction of knowledge from diagrammatic material may be limited. Included in the understanding of diagrammatic representations are the principles of visual perception where lines demarking areas, for example, may be open to differing interpretations if they are not clearly explained as they are added. Tables 5.14, 5.15 and 5.16 show a comparison between the diagram in the textbook and the board diagram where the information has been altered by the omission of arrows and the addition of lines, potentially affecting the information available in the altered diagram.

Diagrams intended to be records of activities did occasionally include the use of arrows denoting movement. The rotation of the Earth indicated by arrows showed a different direction from that shown in the demonstration. Thus, whilst rotating a globe adequately demonstrated the rotation of the Earth on its axis, the direction of rotation was not made clear. The rotation was demonstrated by moving the globe in a clockwise direction. The globe was used so that this movement could be clearly demonstrated, rather than the blue beads, where this movement would not have been visible, therefore whereas the use of the globe was appropriate, the movement made was not.

The use of different sized spheres to indicate the relative sizes of the Earth, Sun and Moon, showed the vast differences in the sizes of the Earth and Moon in comparison with the Sun. It did not show, due to the sizes of the spheres, the differences in the size of the Earth and Moon. On the scale used, the Earth and Moon appeared to be of similar size. This similarity of size was repeated when the phases of the Moon were drawn on the board. Thus on two occasions the representations used indicated that the Earth and Moon were of similar sizes, potentially reinforcing the commonly held misconception about these bodies (Baxter 1989, Trumper 2001).

This selection of appropriate spheres from a selection of eight to establish the relative sizes was followed by a demonstration using a different sphere (the globe) and gestures to indicate the Sun's energy travelling to the Earth. The small blue bead previously selected for the Earth would not have been adequate for this demonstration. The exchange of a small sphere for a large sphere, the globe, which the children would recognise as a depiction of the Earth from their geography lessons, was therefore necessary. In order to fully understand the behaviours and mechanisms operative in phenomena, a description of the processes is needed. Whilst the representational material selected did in some circumstances address the behaviours, indicating the orbital path of the Earth around the Sun, for example, generally only structural aspects were presented and described. The teacher stated in their interview that they felt that children should be given limited amounts of information, enough for them to understand at that time but not more than they could cope with.

Therefore the representations that were used in the lessons were generally fit for purpose in that they:

- demonstrated the physical bodies involved in the phenomena being described
- showed the paths of orbit of the Earth around the Sun
- showed the rotation of the Earth about its axis.

However, there were areas where the representational material was not fit for the purpose in that:

- there were scale changes during use
- mainly structural aspects were highlighted, omitting behavioural and mechanistic processes
- diagrams did not contain all the information – no gestural or explanatory additions were included

- diagrams from published sources were altered for the children to copy resulting in missing or removed content
- children changed the diagrams as they copied them into their exercise books.

The representations used by the teacher were sometimes used once and occasionally the same materials were used to further illustrate or demonstrate a point. Therefore the teacher considered the representations used in the lessons as being 'fit for purpose'.

6.3.6 Repeated use of representations

Most of the representational material used was described in either the teaching materials for the Spectrum published scheme (Cooke and Martin 2004), the QCA schemes of work (QCA/DfEE 1998) or the Co-ordinated Publishing Group (CPG) book (Parsons 1999). In the interview the teacher stated that they were happy with the materials from the new scheme. The teacher felt the use of the materials had been successful and would use them again in the following year. The materials from the QCA and CPG book (Parsons 1999) had been used on previous occasions and were considered to be appropriate and useful and had been used in the same format.

Some of the representational material, the string model and fan model, were designed to be created in lessons. Once these models had been completed the teacher made no further use of them during lesson time though the fan models depicting the relative sizes of the planets were incorporated into a wall display created by the teacher on completion of the series of lessons.

The 'brainstorm' to decide the contents of the Solar System (Figure 5.1), was not recorded by the teacher or the children and was therefore a representation for that lesson only. The contents of the Solar System were presented as a worksheet (Figure 5.2) which was redrawn on the board later in the lesson. The worksheet named the planets in order from the Sun, and as the diagram on the board was a re-presentation of the worksheet this was effectively the same representation in a different format. The re-drawn worksheet had no further additions made to it and was a revision and self marking exercise.

The string model presented the same information, the order of the planets from the Sun, but with the added dimension of scaled distance from the Sun and from each other. Therefore this was a different representation, in that it used different materials and included the scaled distances.

The fan model depicting the scaled relative sizes of the planets was not related in any way to the previous representations of the Solar System, except to name the planets, and served to show the planets in order of their size. It did include other physical attributes of the planets, namely their perceived colours. The children were given access to a poster which was attached to the board to help them with colouring in the planets. The poster presented the planets in the correct order from the Sun, with their orbital paths marked as lines. The pictures of the planets were arranged to fit into the area of the poster, rather than in a line as presented in previous representations.

The selection of spheres was used only once as the children were only required to choose three from the selection of eight to represent the Earth, Sun and Moon in relative scaled size. The sphere selected for the Sun was used on several other occasions. The sphere representing the Earth was used on one other occasion to show the effect of the Earth's tilt and distance from the Sun. The sphere representing the Moon was not used after the demonstration.

The geographical globe, introduced initially in lesson 7, was used repeatedly to represent the Earth. This allowed the children to see that the Earth was the focus of the demonstration, which would not have been possible with the small, blue bead which was the sphere selected to represent the Earth.
Therefore;

- Most of the representational material was presented once
- Exceptions were the beach ball Sun and the globe Earth.

6.3.7 Representational material and target models for representations

Though few of the representational materials were used on more than one occasion those that were were used to depict the same entity, the order of the planets from the Sun. Therefore, this target, the order of the planets, was represented in three different formats: the string model, the worksheet and the re-drawn worksheet diagram on the board.

Therefore:

- Target models were represented by more than one form of representation – in the case of one target only.

6.4 Cognitive coherence in representational material used in the science lessons

The organisation of the lessons enabled the children to focus on the subject matter of each lesson and relate it to the context of the previous lesson. The periods of representational use which occurred in the lessons were summarised in recaps and by notes in books. Orienting the children to the area of study and reminding them of previously covered work is excellent pedagogical practice providing the children with plenty of opportunity to 'tune in' to their science lessons and 'out' from whatever activity they had been engaged in prior to entering the science classroom so making the lesson relevant and potentially meaningful (Ausubel and Robinson 1973, Osborne and Wittrock 1985). This gives an insight into the way the study teacher understood learning occurred.

6.4.1 The teacher's understanding of teaching and learning

The inclusion of representations in science lessons was part of the pedagogical practice of the teacher. The practice of the teacher was evident from the video recordings. Generally a direct teaching method was employed. The children were presented with a number of facts on which they would be tested on completion of the topic and again at the end of the term. The teacher expected the children to sit still, face the front of the classroom, pay attention during explanations, copy notes quietly and be fully involved in any practical activities. The teacher displayed many characteristics of an excellent didactic practitioner (Wragg 1991, Denicolo and Pope 2001, Joyce *et al.* 2002).

An overview of the series of lessons showed a well ordered series of lessons addressing the relevant information in accordance with the National Curriculum for Science programme of study Sc4a,b,c,d (DfEE 1999) and QCA scheme 5e (QCA/DfEE 1998). The lesson series also included information beyond the scope of the Key Stage 2 requirements, namely seasonal change (Table 5.1).

The lessons presented the children with what the teacher described as 'a journey through the Solar System', starting with the contents, moving to the order of the planets, the relative distance of the planets, their relative sizes and their physical attributes. Once these facts had been established, the 'journey' moved the children to observable phenomena. The teacher stated in their interview that children of this age (9 – 10 years old) should not be presented with too many complicated facts, but on the other hand they should be given accurate facts. This notion of children's learning tends to indicate that learning is about the transmission of facts, which would accord with the didactic practices observed in the classroom.

The model building activities provided the children with reinforcement of the facts they had already been told. They gave no opportunity for the children to test their ideas and were in fact technically difficult for children of this age. The teacher, however, felt the children had enjoyed constructing the models and stated the intention of creating them again in the following year. Whether this happened is not known.

The representational materials used to illustrate the factors involved in the topic were presented in a mixture of modes, most commonly diagrams which were drawn slowly with time for the children to copy. Most parts of the diagrams were explained as they were added. This allowed the children to make sense of the marks in the diagram enabling them to construct meaning from them, both as they were drawing and at a later date. Some of the explanations were given gesturally, the path of an orbit for example, but not added to the diagram. If the children were able to construct meaning from the diagram as it was drawn, then the fact that the gestural movement was not recorded would be immaterial, it would be an implicit part of the diagram. The construction of 'accurate' diagrams and accompanying notes in the children's exercise books also suggests that facts are a key aspect of science knowledge in this classroom. The teacher's insistence in the interview that diagrams should not contain any extraneous information, nor challenge the children with too much information, could have led to a formal decision about what to include and exclude in copying from the textbook to board.

Analysis of the textbook diagrams (Tables 5.14, 5.15, and 5.19) shows that they contain mainly references to the structural aspects of the phenomena they are representing.

Occasionally behavioural aspects are mentioned or indicated by arrows, but in no case was there any indication of the mechanisms involved in the phenomena. Removing informational content from already informationally compromised diagrams certainly reduces the amount of 'clutter' the children have to read and copy, but it also potentially reduces the knowledge that can be constructed from such diagrams. Again, this probably resulted from the teacher's insistence that diagrams should be uncluttered and the factual information of the materials, limited.

Therefore the teacher's understanding of the way learning takes place appears to be:

- that science is a body of facts to be learned
- that these facts should be given to children
- that the facts should be accurate
- that the facts should be in line with the perceived level of cognitive development
- that any representational materials should be examples of these facts
- that notes recorded in exercise books are lists of these facts to be learned for summative testing
- that children in the class should sit and listen whilst they are told the appropriate (in the eyes of the teacher) facts
- that activities can be undertaken to reinforce these facts
- that activities should be enjoyable and interesting for the children
- that demonstration of the facts via representational material, both in the form of objects and diagrams, is sufficient for the children to understand and consequently learn
- that diagrams should be a clear depiction of the facts the children need to know.

These ideas about the way children learn take little account of the possible misunderstandings about scientific phenomena which may be held by the children. The teacher was, however, aware that children did have different interpretations about scientific phenomena.

6.4.2 The teacher's awareness of common misunderstandings in science topics

The teacher stated they were aware that children held different interpretations of scientific phenomena, thought to be a combination of poor teaching and children's interpretation of these lessons. They teacher did not appear to be aware that the children formed their own mental models of experiences of scientific phenomena encountered in their everyday lives.

One misunderstanding that the teacher was particularly aware of was that of the seasonal change being caused by the Earth's proximity to the Sun. The demonstration, using the small blue bead 'Earth' and the beach ball 'Sun' very effectively demonstrated that the tilt of the Earth's axis produced an insignificant change in proximity to the Sun, thereby indicating that seasonal change did not result from the Earth's nearness to the Sun. Though this was a very effective demonstration, it was not followed by any other explanation as to the actual cause of seasonal change until the following lesson.

In the early lessons (1, 2, 3 and 4) the contents and structure of the Solar System were being studied in terms of the positions of the planets. In lessons 2 and 3 the relative positions of the planets and Sun were described in line from the Sun. This is a commonly held misunderstanding; the structure of the Solar System is described as the planets in an equally spaced line from the Sun (Sharp 1996). The repeated depiction in the worksheets, board drawing of the worksheet and the string model effectively reinforced these ideas.

In lesson 7 the children were required to select appropriately scaled spheres to depict the Earth, Sun and Moon from a selection of eight spheres. The teacher was surprised by the children's choices. Initially the children chose the largest sphere for the Sun and the next two largest spheres for the Earth and Moon. It is a common misunderstanding that the Earth is relatively large in comparison to the Sun and that the Moon has the same dimensions as the Earth, based on direct observation of these bodies in our sky (Schoon 1992). Once the error was apparent, the teacher did address the children's ideas by allowing them to reselect Earth and Moon spheres based on the agreed decision that the Earth could not be depicted by the football because of the dimensions, given by the teacher, involved. Having established the relative sizes of these three bodies, the lessons moved to their interactions in observable phenomena.

In lesson 8 the teacher used the globe to demonstrate the period of the Earth's rotation on its axis, a day. After the demonstration a child was asked to repeat the period. The response was that the Earth took 365 days to turn on its axis. There was confusion amongst the children about the period of the Earth's rotation on its axis and the period of its orbit around the Sun. This is another common misconception of which the teacher was previously unaware. Again the teacher, once made aware of the confused ideas, demonstrated the facts of the rotational and orbital periods of the Earth. This is an interesting finding as the topic had been taught by this teacher on other occasions in previous years.

A similar confusion about the period of orbit of the Moon was revealed in lesson 12 when the phases of the Moon were being discussed. On this occasion the teacher told the children the period of orbit without any demonstration or explanation.

Therefore it appears that though the teacher stated they were aware of common misunderstandings likely to be held about the topic of the Earth in Space, the reality was that:

- there were misunderstandings they were unaware of
- any misunderstandings held by the children were thought by the teacher to result from inadequate teaching
- the teacher expressed no awareness of the fact that children form their own ideas about scientific phenomena as a result of their own experiences.

The representational material was selected on the basis of illustrating the points in the lessons adequately. This was the teacher's stated intention. The teacher's lack of awareness of all the likely common misunderstandings held by the children will have contributed to their decisions during selection of materials and the way these were used during the lessons.

6.4.3 Representations and common misunderstandings

The fact that the teacher showed limited awareness of many of the common misunderstandings may have influenced their selection of representational materials. The materials used, however, did address some areas of misunderstanding. This is possibly because the materials were from published schemes and their designers were aware of the common misunderstandings and had accounted for this in their design.

During the first lesson the children were asked to name the contents of the Solar System. Their contributions were put on the board in a series of lists, enabling them to see the objects contained in the Solar System and those outside. They were expected to contribute without any prior information being given to them, relying on information they already knew or could guess at from other contributions. There was no attempt to describe the structure of the Solar System at this point.

The following lessons reinforced the contents of the Solar System and included properties such as order and the distance apart of planets and their relative sizes, presenting them as labels and circles. Though there is no evidence to show that the children had already been taught about the spherical nature of the planets, one of the children, 'J', in the initial interview did refer to the Earth as being a sphere. Child J had been selected for the interview group by the teacher on the basis of a high score in the end of previous topic test. Not all children may have been as confident with the notion of the Earth, and other planetary bodies, being spherical. It might therefore be reasonable to assume that the children had already encountered the idea in previous science lessons which was known by the teacher. The diagrams constructed on the board depicted the Earth and other bodies as circles with no attempt to describe their spherical nature.

Where diagrams were constructed on the board the teacher used diagrams from textbooks as prompts. The textbook diagrams were coloured and shaded, giving information about the spherical properties of the Earth and Moon. These aspects were not transferred onto the board. The aspects which were included were those thought by the teacher to be useful for the children's understanding of the phenomenon being illustrated and these aspects did not include information about the properties of the structures drawn, such as shading to indicate dimensionality. That the teacher did not transfer the shading may have been confusing for some children who did not understand that the circles drawn on the board represented spheres. It also suggests that the teacher may have expected the children to be able to imply that the circles denoted spheres.

Whilst the teacher copied diagrams from textbook to board, the dimensions of the illustration changed. The children had to change the dimensions again as they copied from the large board onto an A4 page. They added their own colours to their diagrams without any reference to the textbook the teacher was using. Those diagrams that the researcher saw in the children's books did not have any shading to indicate spheres rather than circles, though colours had been added, blue and green to the Earth circle and grey to the Moon circle, indicating some conceptual understanding of the manner in which the Earth and Moon are generally represented.

Though the teacher added some extra information to the diagrams as they were constructed in the form of gesture and explanation, this information was not always included in the diagrams themselves. So, where the rotation of the Earth was mentioned and shown via gesture during the construction of one of the diagrams, this information was not drawn on the diagram. When the children viewed the diagram at a later date, they might or might not have remembered this additional information. If the additional information, given gesturally or verbally, did not accord with their understanding, their mental model of the phenomenon at that time, it is unlikely that they would understand or remember any additional information not recorded in their books. Any misunderstandings about the direction of orbits would remain unchallenged.

Therefore the representational material used in the series of lessons:

- addressed one commonly held misunderstanding in respect of seasonal change
- did not address other commonly held misconceptions
- in some cases potentially reinforced commonly held misconceptions.

Given that the commonly held misconceptions about the phenomena in the Earth in Space topic were generally not known by the teacher nor addressed, the potential for promoting construction of accurate and appropriate knowledge during the series of lessons was substantially reduced.

6.4.4 Knowledge construction from representational material

The teacher's pedagogical practice, limited awareness of possible misunderstandings and strong views about appropriate representation design all contribute to the potential for knowledge construction from the material presented to the children.

The 'cognitive pathway' designed by the teacher for the children to follow through this series of lessons is initially sensible and appropriate, starting from the overall very large structure of the Solar System and moving towards observable phenomena. In lessons 5 and 6 the children were given a list of objects outside the Solar System which actually include objects found in it. This potentially causes confusion when compared with the facts given in previous lessons. The fact that the possible misunderstandings the children were likely to bring to their science lessons were not accounted for either in the factual material of the lessons or the selection of representational material will have had a radical affect on any potential knowledge construction over the course of the series of lessons.

The representational materials on analysis had mainly structural aspects available in their design. Aspects added by the teacher tended to stress structural aspects, though some behavioural aspects were added verbally and gesturally. Verbal and gestural additions are ephemeral in their nature and these additions were not always included on written material given to the children.

The children were given no opportunity to question either the lesson content or the demonstrations using the representational material. Indeed, they were given no opportunities to verbalise their ideas which in turn would limit the possibilities for re-structuring their mental models of the phenomena under consideration (Driver *et al.* 1994, Gilbert and Boulter 2000, Gobert and Buckley 2000).

The lessons proceeded in a reasonably coherent manner, moving from the overall structure of the Solar System to the inter-relationships of bodies within the system. This was achieved with reference to the structural aspects only and gave the children relatively little opportunity to consider why these events might be occurring.

The recording of the events in exercise books by copying diagrams and text from the board allowed the children to have a version of the events, but these records were mainly the structural components with very few references to the behaviours or mechanisms operating on the structures. Analysis of the diagrams in the textbooks indicates that there were layers of information missing, limiting the potential for knowledge construction from them. In addition, the teacher translated the diagrams as they copied from the textbook by removing many visual clues which may have contributed to understanding the behaviour and mechanisms of the events, further limiting their potential for knowledge construction. The children copying the diagrams also changed the contents and dimensions of the diagrams, again altering the potential for knowledge construction.

Diagrams were often reiterations of demonstrations using physical objects. The objects used were analogous depictions of bodies in the Solar System, which were not referred to in the construction of the diagrams. This implies that the teacher thought that the children were able to transfer analogous information from an object to a drawing. As both the diagrams and the objects used in demonstrations were mainly representing the structural aspects of the Solar System, as revealed by the analyses described in the previous chapter, little reference was made or made available about the behavioural or mechanistic elements operative in the inter-relationships of the objects.

Where there were references to the behaviours of the bodies in the Solar System, the description of orbits for example, the way they were described implied that they were objects and therefore a part of the structure of the bodies rather than resulting from behaviours and mechanisms operating between them.

Therefore the representational material used in the series of lessons:

- referred to the structural aspects of phenomena
- had several layers of information missing
- were changed as they were drawn onto the board
- were changed again when the children copied them into their books
- were presented as a body of facts
- contained few or no references to the behaviours or mechanisms operative
- did not require the children to engage cognitively
- presented limited potential for the construction of knowledge.

The representational materials used in the series of science lessons, therefore, were in fact a series of demonstrations of facts about the Solar System and required only limited active cognitive engagement from the children in the class. The materials were informationally compromised, further limiting the potential for knowledge construction from them. This might reasonably account for the fact that the children in the second interview were adamant that seasonal change was due to the tilt of the Earth but were unable to explain how or why.

6.5 Summary of conclusions

The themes informing the development of this study, teaching and learning, mental models and misconceptions, representations and the way they are viewed, are all related and encompass knowledge construction in science, visual literacy and the influence of psychology in these areas. The conclusions drawn from the results of this study can be summarised thus:

- Four different modes of representational material were used over the whole period of the lessons.
- This representational material was a combination of teacher models and commercially produced materials.
- The teacher had clear criteria for selecting the materials based on their personal interpretation of them.
- The representational materials were introduced as explainers of facts.
- The explanations of facts were structural in content, therefore objectivising the phenomena illustrated.
- Representational material was used frequently – in most lessons.
- The materials were combined with explanations and gestures.
- The materials were used in the context of the lesson.
- The materials were appropriate in their illustration of the physical attributes of some phenomena.
- The materials were not appropriate when they:
  - introduced scale changes without explanation
  - stressed only structural aspects of phenomena
  - did not include gestural and explanatory additions (in diagrams)
  - simplified published materials and therefore altered them
  - were altered again by the children.
- Some representations were used repeatedly and were therefore context-dependent.

- The same material was sometimes used to illustrate different targets.
- The teacher had a traditional teaching style and consequently:
    - viewed science as a body of facts to be learned by transmission rather than engagement
    - considered some facts to be cognitively difficult for the year group
    - had limited knowledge of potential misunderstandings the children might hold – and as a result did not address them.
- The representational material was such that it:
    - did not address many common misunderstandings
    - in some instances potentially reinforced misunderstandings
    - was changed by both the teacher and the children indicating that knowledge constructed from the material was possibly incomplete and/or inaccurate
    - did not present a cognitively engaging or coherent pathway for knowledge construction.

These conclusions will be discussed in terms of the themes identified and discussed in Chapter 2 and the issues arising from the conclusions in relation to these themes.

6.5.1 Issues for teaching and learning

The current government recommendations to introduce constructivist principles into the primary classroom are underpinned by research into how children learn science in the classroom (Driver *et al.* 1994, Osborne *et al.* 1994). Constructivism promotes learning as a dynamic and social process in which the teacher acts as facilitator for promoting inquiry, discussion and collaboration to encourage active development of understanding in the community of the classroom (Driver *et al.* 1994, Boulter and Gilbert 1995). This is generally achieved by creating opportunities for children to ask questions, discuss answers in small groups and pose further questions for investigation. Whilst this might be difficult to achieve in a topic such as the Earth in Space, it is feasible to do so (ASE 1990, Mant 1993, Osborne *et al.* 1994, Keogh and Naylor 2000).

The direct teaching style adopted by the study teacher ensured that the knowledge content of lessons remained firmly under the control of the teacher who also directed the pace of lessons, introducing a definitive structure for delivery of the content. Therefore lessons become curriculum driven in that a certain amount of knowledge was required to complete studies successfully. In the study school all Year 5 children covered the same curriculum material each year. Therefore, the constructivist notion of the child at the centre of their learning was not a feature of lesson preparation or planning. These types of lesson leave little or no opportunity to engage children in their own learning other than in a passive manner. Other aspects of effective teaching styles such as posing challenging questions and giving direct feedback were not employed by the study teacher (Harlen 1995, van Zee 2000).

Millar and Osborne (1998) suggested that as part of the change in teaching styles and to promote constructivist principles in science education, teachers should question children, using open questions which would access mental models and promote thinking. In the study school all the questions asked were closed questions generated by the teacher and addressed to specific children and required a 'right' response. If the response was not the required one another child was chosen to answer. No discussion of 'wrong' answers was pursued. Closed questions do not facilitate challenges to children's thinking, nor encourage further questions (van Zee 2000). Questions were used to check the children were listening to the explanations and also as a control tactic, making sure that the children remained engaged with the facts of the lesson.

Though the atmosphere in the classroom appeared relaxed, despite the continuous control tactics adopted by the teacher, any attempt by the children to ask questions was discouraged, both verbally and gesturally, with flat handed 'stop' gestures being directed towards the questioner, so any areas of explanations which were not understood could not be clarified. One or two children did manage to voice ideas, usually as asides whilst the teacher was talking. These interruptions were either ignored or silenced either verbally or by 'stop' gesture. Not only does this encourage an atmosphere of factual knowledge being the key to understanding, it discourages children with incomplete understanding from participating, in case they fail to give the correct answer. This also supports the teacher's stated ideas about science knowledge as accurate facts to be told and perpetuates the impression of the teacher being the 'fount of all knowledge', an expectation often held by pupils, staff and parents and those responsible for organising the curriculum and certainly prevalent in the study school.

In order to maintain silence for explanations and instructions, the teacher 'sshed' the class repeatedly, often in mid-sentence. Incidents of lack of concentration by any of the children were noted, again, often in mid-sentence. This put pressure on the children to behave appropriately in order that their name and behaviour was not brought to the attention of the rest of the class. Though the videos of the children have not been analysed to identify their behaviours in any detail, it is apparent from watching them that there are many occasions where the children were not listening to the teacher.

There are a number of possible reasons for this lack of concentration. As the teacher wrote information on the board in the form of notes to be copied, the children would know that if they missed anything, it would be in the notes. This activity did not engage the children and presented no conceptual challenges to them. As the children were rarely involved or required to think whilst the teacher was talking, it is possible they were de-motivated, leading to their fidgety behaviour.

The teacher was very clear about accurate factual information as knowledge to be communicated, but not all the facts, judging at what point to withhold information. Thus it is unclear why seasonal change was included in the series of lessons, particularly as it is no longer part of the science curriculum at this level. The only justification would appear the teacher's awareness of the common misunderstanding.

The notion that children should be taught within their perceived cognitive development zone is Piagentian, as children of a particular age are unable to assimilate and understand some aspects of the science being taught, due to cognitive immaturity. Teaching science as facts presumes a 'tabula rasa' notion of learning. The points at which decisions were made regarding the appropriateness of lesson material were not stated by the teacher, nor were they clear from the lessons.

The difficulty with a didactic style of teaching is that it allows no opportunity for children to test their ideas against others and therefore any misunderstandings are unlikely to be sufficiently challenged for mental models to be reformulated or adapted in any significant way.

6.5.2 Issues for mental models and misunderstandings

The teacher stated they knew about and understood the importance of potential areas of children's misunderstanding and the importance of addressing these areas during teaching. Misunderstandings only become apparent when individuals express their mental models (Gilbert and Boulter 2000). Encouraging discussion by posing challenging questions or facilitating presentation of ideas allows expression. Direct and closed questions posed and 'correct' answers assume no misunderstandings are held; therefore no opportunity for discussion is afforded and no individual mental models are expressed.

Discussions with the teacher prior to the commencement of the study suggested that the promotion of discussion around areas of misunderstanding was regarded as important. This fact was not referred to in the interview after teaching and, in fact, no opportunity for discussion was afforded to the children during the lessons.

The teacher often referred to 'discussions' during introductions to lessons, and felt that this was what was happening in the classroom. These were in reality periods of teacher explanation to which the children listened. Misunderstandings are unlikely to be recognised or highlighted if discussion takes the form of teacher explanations.

Explanations have been suggested to be appropriate when they "facilitate and suggest directions for, as oppose to inhibiting subsequent questioning" (Gilbert and Boulter 1998 p87). The expectation during explanations was that the children would listen quietly, as information was given, therefore neither suggesting nor facilitating further directions for questions. In that sense these periods are more descriptions than explanations as they were not prompted by any questions.

The lack of opportunity for discussion severely limits opportunities for the identification of alternative ideas. Misunderstandings about the structure of the Solar System (Summers and Mant 1995, Sharp 1996, Lemmer *et al.* 2003) were not addressed and were in fact potentially reinforced by the representational material the children were presented with.

The relative sizes of the Earth, Sun and Moon is another area of documented misunderstandings (Sneider and Pulos 1983, Jones *et al.* 1987, Lemmer *et al.* 2003). The children clearly demonstrated these misunderstandings in their selection of spheres. The teacher's response did not contribute to changing misunderstandings about their relative sizes.

Thus, little account was taken of the children's mental models, which did not enable access to any potential misunderstandings the children may have held. Therefore the representational material selected by the teacher provided an illustrative role for the facts being disseminated, rather than serving as a prompt for expressions and discussion of individual ideas.

6.5.3 Issues for representational material

The teacher's notions about the way children learn as outlined above and evidenced by the video recording will have contributed to their selection of representational material. The strong feelings expressed by the teacher about the content and appearance of diagrams in particular also influenced the drawings on the board.

Diagrams, though perceived as simple expressions of objects or events (Hartley 1994, Tversky *et al.* 2000), require well developed visual literacy skills to decode (Sturken and Cartwright 2001, Unsworth 2001). Teachers regularly change published materials when preparing them for use by children without apparent regard for any visual literacy skills (Peacock 2001, Peacock and Cleghorn 2004). The study teacher changed diagrams from books. The children copied these diagrams, changing them again by adding their own colours and missing out lines and/or arrows that were included in the teacher's diagrams. There is no research which covers the way in which children copy notes and diagrams from the board. The aim of the notes and diagrams on the board, in this study, was to ensure that all the children had the same facts for revision purposes. In reality the children had different diagrams from the teacher.

The reason the teacher used science textbooks as prompts may be related to the fact that science texts are regarded as accurate (Lemke 1990). Re-drawing the material from the book onto the board might be seen as a way of simplifying complex scientific texts and diagrams for children. Removing aspects of diagrams potentially changes the meaning which can be generated from them. If children are not engaged in the creation of diagrams, then the potential for constructing meaning from a later viewing may be compromised. The fact that the children changed the diagrams they copied into their books suggests that their understanding was incomplete and that they were unable to 'read' the diagram, copying to the best of their understanding. The teacher made few corrections on the children's work suggesting that they were unaware of the changes the children had made or of the significance such changes might have on the construction of knowledge from these diagrams.

There are many problems with the structure and content of images in science textbooks and the analysis systems used for this study support the findings of these other studies. The analysis systems allow the informational content of representational material to be determined and for additional information added in the form of speech and gesture to be taken into account.

It is only as a result of these analyses that the differences between the textbooks, board diagrams and children's exercise books could be established.

Gestures are an integral constituent of classroom communication (Alibali and Goldin-Meadow 1993, Crowder 1996, Goldin-Meadow 2004). The study teacher used many gestures to accompany explanations and descriptions of representational material. Children are adept at reading gesture (McNeill 1992, Crowder & Newman 1993, Goldin-Meadow 2004), so the significance of gesturing about, for example, orbital direction in the opposite direction to reality needs clarification, in terms of how children might read directional gestures made by teachers. A gesture can convey meaning where speech on its own may be insufficient, forming another level of communication and description from which meaning can be generated and therefore allowing the information being presented to be more completely accessed. Gestures can convey movement in static objects and images and clarify positional structures and directions of arrows, but they need to be comprehensible at the time and therefore become an intrinsic part of the object or diagram (Ogborn *et al.* 1996, Goldin-Meadow 2004, Norris 2004).

Gestures used in conjunction with objects, such as the globe and the numerous spheres used to illustrate the structure of the Solar System, can give meaning to these objects in the context of their use. If these objects are then re-designated to represent other objects in differing circumstances, this is likely to present the children with cognitively unsupportable challenges.

Research shows that the language and diagrammatic images included in textbooks are both difficult to read and to interpret (Larkin and Simon 1987, Chan *et al.* 1992, Mayer 2002, Stylianidou *et al.* 2002). Therefore representations which contain implicit information in their construction require highly developed levels of cognitive development and visual literacy skills to interpret. These are factors which may not be taken into account when representative material is selected for use in the classroom.

There are, however, a number of factors which can be identified from the conclusions of this thesis as having an effect on the choice of representational material in the classroom, summarised in Figure 6.1. The figure describes the connection between factors internal to the classroom, concerning the teacher and the children, and the factors external to the classroom imposed by authoritative bodies such as the government and school. Parents, though not studied in this thesis, are included in these factors partly because they have operated choices about the school and the education of their children, and therefore implicitly support its style of teaching and attitude to learning. Also included in the factors are the authors and publishers of materials used in many primary schools. Their understanding of the effects of children's visual literacy, curriculum content and scientific knowledge of this content, and its relationship with teachers' and children's knowledge, will inform the design of materials and the content thought to be appropriate for inclusion.

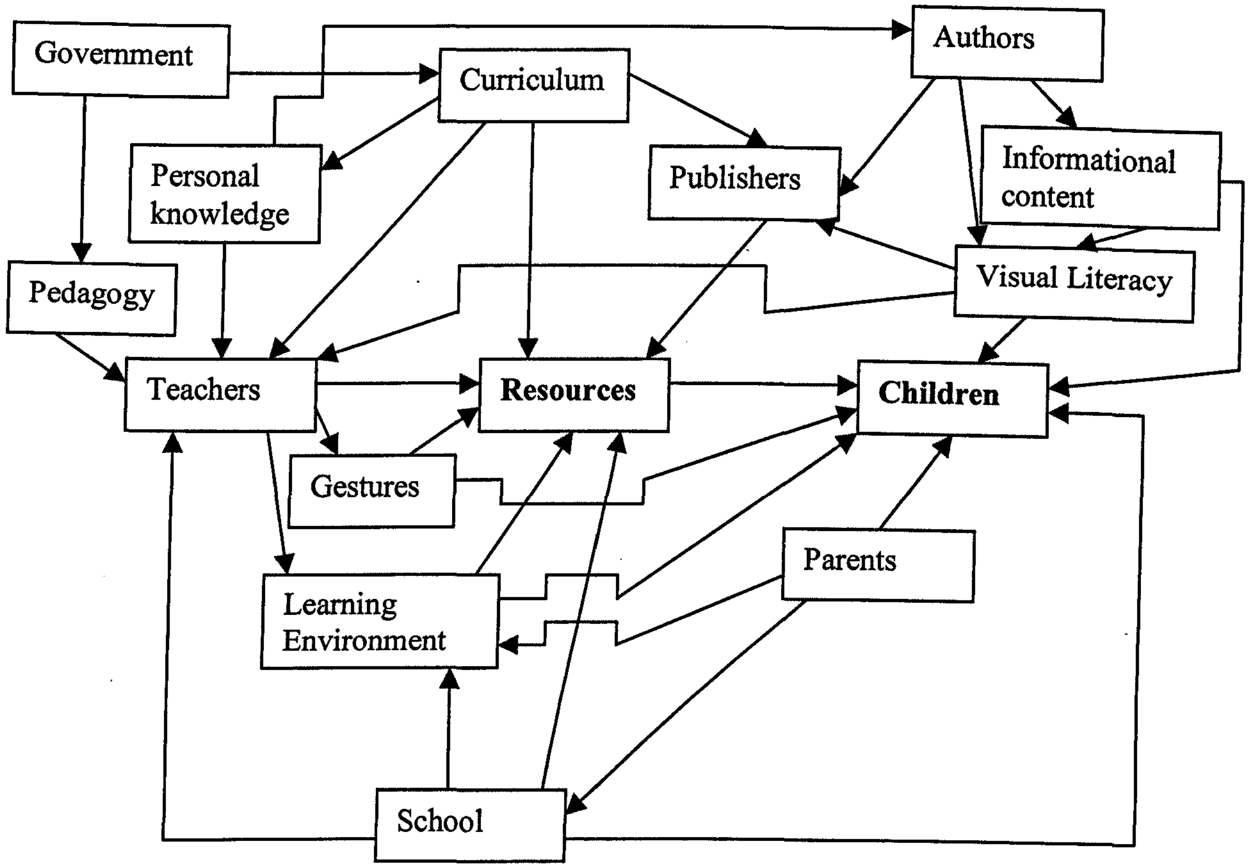

Figure 6.1 Factors potentially affecting the choice of representational material (the resource).

In addition, there are factors identified by this thesis as affecting the use of representational materials in the science classroom emerging from the conclusions drawn from the results of this study. Figure 6.2 proposes some ideas about the connection between choices and uses made of representational materials. In some cases the choices and uses are interrelated, for instance the pedagogy of the study teacher appeared to influence both the way they chose materials for use and the use made of the materials in lessons. Also, the teacher's mental model of aspects of the topic is implicated in both the choice and use of materials, as they chose materials which were missing, in terms of the analyses used in this study, elements which would have contributed to the formulation of a coherent cognitive pathway but instead, by their absence did not address potential misunderstandings.

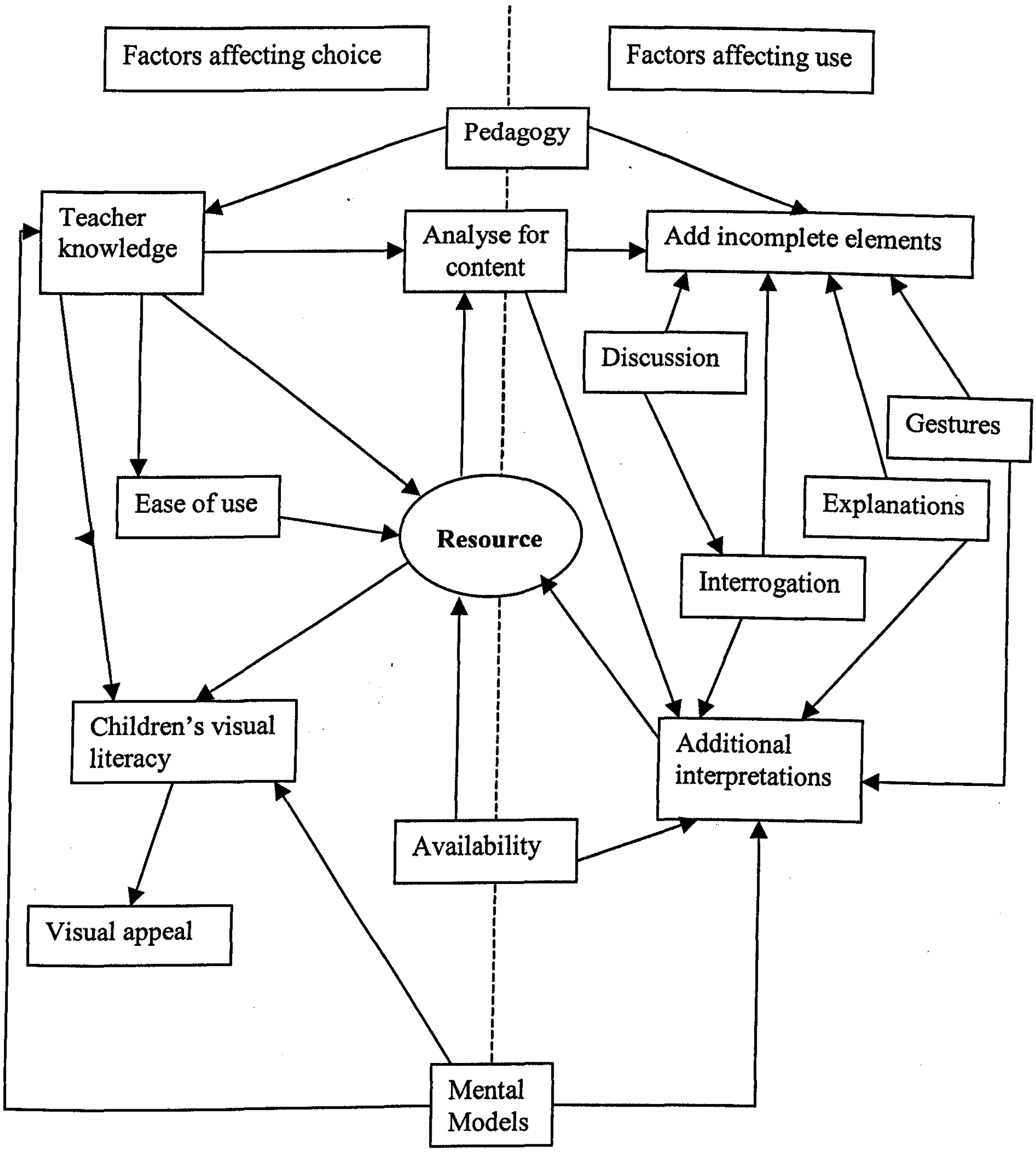

Figure 6.2 Factors affecting the choice and use of representational material.

Figures 6.1 and 6.2 identify the relationships between the choice and use of representational material in the classroom, some of which have not been identified by previous research and therefore constitute a contribution to knowledge in regard to the use of representational materials in primary school science lessons.

Specifically:

- The effect of pedagogy on the selection of materials.
- Understanding of the contribution of mental models to learning, interaction with and selection of materials.
- Teachers' knowledge of levels of visual literacy skills required to decode materials.
- The contribution of gesture to the use of materials.
- The effect material design, in terms of its informational content, physical construction and therefore appearance, has on the potential for knowledge construction from materials.
- The provision for cognitive engagement with materials.

The teaching style adopted by the teacher has implications for the choice of and engagement with representational materials. This study identified the representational materials as being used solely as explainers of facts; other teachers may use them for different purposes. Teachers' understanding of the way learning occurs and the implications of the mental models both they and the children take into the classroom appear to have an influence on the choice of materials. Visual literacy skills have already been identified as contributing to potential meaning construction from images and therefore materials used in the classroom, but teachers' understanding of the levels of the skills needed to interpret visual materials do not appear to have been researched.

Chapter 7 discusses implications from the results of this study and proposes areas for further research studies.

Chapter 7

Implications and further research

7.1 Introduction

The results and conclusions from this study highlight areas of teaching with representational material which have not been considered in previous research. The findings have implications for teachers, teacher trainers, curriculum planners and publishers and raise several issues which have not been studied in detail previously.

The first issue concerns practices of teaching in science classrooms. A teacher's pedagogical philosophy has implications for how they engage children in learning activities and relates to their understanding of how learning occurs and the perceived relevance of the knowledge and experience children bring to their science lessons.

The second issue relates to how teachers actually use representational material with their classes, which has implications arising from the style of teaching they adopt in combination with their understanding of how children learn. Representational materials provide a vehicle for allowing access to the otherwise inaccessible and an opportunity for the elicitation of children's ideas and therefore the promotion discussion. The levels of visual literacy required to interpret representational material may not be understood or fully acknowledged by teachers.

A third issue relates to visual literacy; the way drawings, illustrations and diagrams are perceived and interpreted by viewers, and teachers' understanding of these factors and their relationship to the construction of knowledge from interaction with visual materials.

This then leads to a fourth issue with relates to the cognitive engagement facilitated by teachers when using representative material and their acknowledgement and understanding of the levels of information available within the material for coherent construction of knowledge.

7.2 The contribution of this thesis to teaching and learning in the primary science classroom and suggestions for further research

There is a great deal of work still to be done in order to fully understand the way the use of books and other resources used in science lessons impacts on children's learning. The role of teachers in ensuring the resources they choose are appropriate and effective learning tools also needs further investigation. There appears to be no research which investigates the reasons for a teacher's choice of the representational material they use in their lesson. As the models presented in Chapter 6 (Figure 6.1 and 6.2) suggest, there are many factors which potentially contribute to the selection and use of representations. This is certainly one area that would benefit from further enquiry. The reasons for the study teacher's choice of representational materials investigated by this study show, from the responses in the teacher interview and the actual representational materials used in the lessons, that there is an element of disparity between the materials thought to be appropriate and the actual representational material used in the lessons.

It is clear that the use of representational material as tools for teaching and learning is a much more complex activity than merely illustrating phenomena. The pedagogy and consequent teaching style of teacher has been shown to be related to their choice, use and understanding of representational materials. The contribution of pedagogy and teaching style has not previously been investigated in terms of the representational material used in primary science classrooms.

In order to engage children in a coherent learning pathway, the representational materials used should present and be presented in such a way that cognitive engagement is facilitated. This requires teachers to have knowledge about the topic they are teaching sufficient to understand and interact with representational materials they use to teach the topic. The choice of representational also has relevance for teachers' understanding of children's likely understanding of the topic in terms of possible misunderstandings the children are likely to hold. There appear to be no studies which enquire into the way teachers use representative materials to engage children in constructing their own knowledge from the starting point of their current understanding and how they maintain coherence of materials through a whole topic of study.

Representations can never be exact replicas of real situations due to the difficulties of including all aspects of the structure, behaviour and mechanisms involved. There is great potential for teachers to add the missing elements through verbal and gestural explanations when presenting representations, but in order for them to do this they need to be able to assess what information is there in the first instance and then consider ways in which they will add missing information. No previous studies have investigated representational material in terms of their physical construction and the informational aspects of phenomena presented by that construction.

The analysis grids used in this thesis suggest one method of achieving this, though admittedly teachers are unlikely to perform what is actually a detailed and relatively complex process for every representation they are about to use. There is potential to simplify these grids, making them more accessible for immediate use by teachers and an attempt has been made to do this by the researcher. The results require further verification before the shortened grid can be promoted as a tool for teacher use. Testing and validating alternative 'short' analysis grids is therefore one area requiring further investigation if the factors of visual literacy highlighted by this thesis are to be taken further.

The importance of visual literacy in the selection and use of representational materials appears to be under investigated. There are studies which enquire into the textual and visual literacy skills required to decode science textbooks, but teachers' understanding of these skills is not highlighted or accounted for (Mayer and Gallini 1990, Reid and Beveridge 1990, Stylianidou *et al.* 2002). This has implications for understanding how visual material is likely to be perceived and interpreted by children.

In addition to visual literacy skills, children's ability to decode gestures made by their teachers when interacting with representational materials is important. Gesture appears to be a significant element of teaching science (Crowder and Newman 1993, Crowder 1996, Goldin-Meadow 2004). Though there are studies which look at teachers and children gesturing in their lessons (Crowder and Newman 1993, Alibali *et al.* 1997) and comprehensive studies about the meaning of gestures (Neill 1991, McNeill 1992), there appear to be no studies which look at teachers' understanding of gesture and the contribution it might make to their communication with children generally or when using representational material specifically.

Studies which have looked at the gestures children make to communicate their understanding (Crowder and Newman 1993, Alibali *et al.* 1997) have not taken into account the current knowledge about the misconceptions likely to be held by children and how these ideas might be expressed via gesture. It is possible that gesture might provide a further insight into children's mental models if the gestures made by children when they are explaining their ideas are acknowledged and understood by teachers. It is also possible that gestures made by teachers might allow an insight into areas where confidence is lacking both in terms of subject knowledge and practice.

Therefore the contribution of this study to the body of knowledge regarding the teaching of science in primary schools concerns:

- Teachers' pedagogies and teaching styles.
- Teachers' knowledge of visual literacy and its relationship to children viewing visual materials.
- Gesture and its importance in communicating scientific principles.
- Representational materials, their informational content and teachers' awareness of mediating processes to compensate for absent information.
- The use of representational materials to engage children cognitively in individual and personal construction of knowledge and provide a conceptually coherent pathway for learning.

7.3 Using representational material in primary science lessons

Representational material is used in some form in all primary classrooms. It may just be posters and pictures on the walls, but the underlying assumption is that primary age children respond to and engage with visual materials. Representations take many forms. The study teacher used material from textbooks as the basis for the lessons, particularly the diagrams drawn on the board for the children to copy. Though there are a number of studies which have looked at the reliability of the informational content and presentation of representations and diagrams in books (Reid and Beveridge 1990, Stylianidou *et al.* 2002) and some which have looked at the information available for the construction of knowledge from representations and diagrams (Ogborn *et al.* 1996, Kress and van Leeuwen 2001, Unsworth 2001), and studies by Peacock (1997) which have looked at how teachers change published materials for use in the classroom, there are no studies which have actually looked at the way teachers use the representational material they create over a period of time to develop their science lessons.

The results from this study show that the teacher used representational material as explainers of facts; they were demonstrations of individual aspects of the phenomena, points the teacher wanted the children to learn. Analysis showed these periods of representational use concentrated on the structural aspects involved in the phenomena being illustrated and gave no opportunity for other aspects of the phenomena, the behaviours and mechanisms, to be accessed. Therefore virtually all the aspects in the Earth in Space topic were reduced to structures, the physical attributes of objects. Opportunities to add behavioural and mechanistic features of the phenomena, with gesture and explanation, were in the main not taken. The gestures and explanations that were used in combination with the representational materials, stressed structural elements. Though it is important that the structural aspects of scientific phenomena are understood, the behavioural and mechanistic aspects, which supply the how and why of the phenomena, are necessary for accurate and durable knowledge construction about any scientific phenomena.

The use of representational materials as explainers of facts could be as a result of a teaching style which determines activities thought to be appropriate. Other teachers with different teaching styles may place a different emphasis on the use of representational material. This is an area for further study, to compare both the selection and use of representational materials across a range of teachers with different teaching styles.

There is a potential for representations to be used as prompts to stimulate children's questions and discussions, to challenge their current thinking and encourage the formation of new ideas, in any classroom with any style of teaching. This is particularly the case if more than one version of the same event is made accessible. This scenario will only be truly valid in classrooms where discussion is a platform for interaction between the teacher and the children. A community of discourse, where teachers mediate the scientific consensus, the culturally prevalent ideas and the children's interpretation of these ideas, will lead to development in conceptual understanding and the construction of accurate and durable knowledge.

7.3.1 Gesture and representational material

It is acknowledged that teachers frequently gesture during teaching (Goldin-Meadow *et al.* 1999). Children are competent readers of gesture (Neill 1991, Goldin-Meadow 2004) and its value as a teaching device should not be underestimated. Research into teachers' gestures whilst teaching, has concentrated on the gestures made during teaching sessions (Crowder and Newman 1993, Crowder 1996, Goldin -Meadow 2004). There is little research to show what the teachers themselves regard as significant gestures. This would be an interesting path to follow – whether teachers are actually aware of the gestures they make whilst teaching and if they are, whether they consider their gestures as a significant part of their teaching repertoire and if so, if and how they consider they contribute to knowledge construction by the children they are teaching.

This study showed that information, such as directional cues absent from static images or moveable concrete models carried implicitly or absent altogether, could be added by gesture, thus increasing the potential for knowledge construction from representations. The direction of gestures may be significant, depending on the age at which children cease to 'mirror' gesture and are thus able to read them directly. If teachers are unaware of the significance of the gestures they make and children's likely interpretation of these gestures, the information they add to representational material via gesture may be misleading resulting in misunderstandings being created. This is an area which would benefit from further study if teachers' gestures are to be regarded as a serious adjunct to their teaching techniques.

7.3.2 Mental models and the use of representational material

Teachers use a variety of techniques and practices in their classrooms to engage children in learning. These styles of teaching arise from a variety of sources and develop over years of experience in different schools and classrooms. Government initiatives regarding pedagogy may or may not influence actual practices in the classroom. In the study school, it was certainly the case that the expectation from senior staff was that the general style of teaching would be conducted along traditional lines.

Effective teaching and learning has many interpretations. If children are to be judged to be learning effectively when they gain designated levels in standardized tests, then traditional classrooms, where notes are given to be learned, will probably fulfil the necessary criteria. The length of time such rote-learned material is retained is variable, but more importantly it may affect other learning experiences, as remembered facts and partially remembered facts are combined with new experiences and learning situations. Any misunderstandings are unlikely to be resolved unless learners are given the opportunity to interrogate new knowledge in such a way that cognitive conflicts arising can be resolved and integrated into existing knowledge.

Model-based teaching and learning enables this interrogation of personal knowledge against newly presented information, but is reliant on a forum for discussion or expression of initial models. Traditional classroom teaching methods, such as those apparent in the study school, tend not to support or facilitate discussion, where questions from the children may be seen as challenges to authority and teacher knowledge rather than quests for clarification. Questions posed by teachers to children, usually selected children, likely to know the answer, are used as a means of moving the topic forward (Lemke 1990, Sizmur and Ashby 1997), effectively using these children as teaching aids, rather than including them in the resolution of ideas. Using representations as teaching aids will support this notion if the representations are used as visual presentations of facts rather than opportunities for challenging the children's current understanding.

Whilst it is apparent that many of the resources available to teachers may be inadequate for use as a single representation of a phenomenon, this then provides an ideal opportunity for challenging current thinking and moving towards the current consensus of scientific knowledge, by combining a number of different types and interpretations of the same phenomena, producing potential conflicts. These conflicts can then be resolved by questioning and explaining by individuals and groups, so that a consensus is reached, which can be compared with the 'scientific' explanation. Knowledge and understanding gained in this way is likely to be more durable, flexible and transferable, having been generated by individuals. Knowledge gained via cognitive challenges which are resolved appropriately is more sustainable than knowledge learned as a body of facts. In addition, the ability to challenge personal understandings in the light of new information enables and sustains cognitive development and encourages and extends thinking strategies and knowledge construction from the new experiences.

The study teacher used representations in a way which required very little cognitive engagement from the children. Whilst it is unrealistic to expect to engage all children all of the time in classroom activities, participation in the creation of knowledge necessitates engagement at some level. If children's mental models are not taken into account by facilitating cognitive engagement with the materials and content of lessons there is a very real possibility that their current understanding will not be challenged sufficiently, leaving the potential for the retention of scientifically inaccurate mental models.

7.3.3 Representational material in the classroom

Several research studies have found that representational material may not be all it seems, particularly representations in textbooks (Reid and Beveridge 1990, Mayer *et al.* 1996). The analyses of representational materials used in this study showed that there were levels of information missing, limiting the meaning that could be constructed from them. Further investigations could be extended to include other modes of representational material to ascertain whether similar aspects of information are routinely omitted or whether omissions are determined by the mode of media.

Whilst the analysis indicated that many representations contain only partial information, this need not be an enormous cause for concern. It is almost impossible to ensure that all aspects of phenomena or situations are included in any form of representation, there will always be compromises made in terms of dimensions, movement or colour. This situation can be used to the teacher's advantage by using more than one, ideally three, forms of representation, forcing comparisons of aspects and therefore promoting questioning and discussion in terms of individual understanding of each of the alternatives. Representational material presented in this way need not all be of the same type or mode, all from books for example, but should cover the same area to be represented. In this way each will contain similar features but these are likely to be presented differently.

Studies involving children's use of text books or informational books, (Reid and Beveridge 1990, Stylianidou *et al.* 2002) suggest that there is a significant problem with their use at the secondary level. Accessing science texts is more commonly an activity children will engage in outside the classroom, or in addition to their work in the science classroom, for example, for carrying out 'project' work. The levels of literacy, particularly visual literacy, required to access information in both textbooks and informational books appears to have attracted spasmodic research over a period of many years (Larkin and Simon 1987, Stylianidou *et al.* 2002) and has certainly not been investigated from the teacher's understanding of levels required to access different forms of illustrative text in any media.

Peacock and Miller (2004) have identified areas of concern in the use of text material in the classroom suggesting that much of what is available in the many and varied formats is under or inappropriately used. In addition to this, material is often linguistically too complex for its intended audience, the children (Lemke 1990). This is a matter for further investigation and will require negotiation with publishers of materials for schools, to discover the criteria used for their creation and production.

The use of models also requires appropriate levels of visual literacy for children which may be assumed by teachers. The idea that a three dimensional model of a phenomenon is a replica of reality has an effect on the way such representations are perceived. Though there is an increasing awareness of the visual aspects of education, it is still a relatively new field of enquiry with potential scope for altering the manner in which teachers regard the representations they use with children.

Representations cannot carry all the information of a 'real' situation and must therefore have some analogous aspects to them. Mapping these analogous aspects onto the real situation will inevitably break down to the point where the mapping becomes illogical, but this is unlikely to occur at the same point in different interpretations of the same phenomenon. There may also be points at which the analogy represents inaccuracies, such as the teacher moving the torch, representing the Sun, rather than the globe, suggesting a geocentric rather than heliocentric arrangement. The extent to which these factors are considered by teachers appears to be unknown, and ties in with the conceptual leaps teachers make and children experience in the use of representations.

The research conducted into the use of textbooks in science lessons (Larkin and Simon 1987, Reid and Beveridge 1990, Stylianidou *et al.* 2002) suggests that they are not necessarily as useful as teachers would wish them to be. This could be, as this study has found, because they do not contain all the information needed to present a phenomenon appropriately. Teachers often change the content of textbooks either presenting them in the form of worksheets for their classes (Peacock 1997) or, as was the case in this study, using them as prompts for producing diagrams on the board. Peacock and Miller (2004) found that teacher trainers actively encourage trainee teachers to construct their own material from examples of published material. The level of visual literacy required to do this effectively, combined with the well documented levels of inadequate scientific knowledge among primary school teachers (Summers and Mant 1995, Parker and Heywood 1998), suggests that these teacher-produced materials may be less than adequate for presenting cognitively coherent teaching materials (Peacock and Miller 2004).

The translation aspect which this study found to be present as the teacher used textbook material as a prompt for drawing diagrams on the board for the children to copy had been noted by Peacock (1997) when teachers produce worksheets for their classes. Whilst there is nothing wrong with using textbooks as prompts, it should be noted that by re-drawing diagrams, for instance, some features may be removed or altered, either as a result of the materials available (the right coloured board pens), drawing expertise, or a desire to simplify. Also the scale of diagrams is changed as it is moved from the textbook to the board. The children copying from the board, book or a worksheet translate again in terms of both individual elements of diagrammatic construction (lines and arrows for example) and scale as they move the work from what they see on the board into their science exercise books.

The teacher in the study required all the children to have the same diagrams in their books for revision purposes. The diagrams appeared to contain all the same marks as the teacher's board diagram, but some children had spontaneously added colours not included on the board diagram. If children can add information in this manner, is it possible that they might add or omit other information, detrimental to the interpretation of the diagram at a later date. On the other hand, by making additions the children are personalising their work and thereby possibly indicating their mental model of the phenomena being illustrated, a useful pointer for teachers aware enough to note the changes. This brings into focus the reasons for teachers requiring primary school children to make notes in exercise books.

The reasons primary children are required to make notes in exercise books is an area of research which has not been accessed in any detail for this study, but a straw poll of colleagues suggests that testing, and therefore revision, is one of the key reasons, followed by recording lesson contents for other adults (head teachers, parents, inspectors). If children do not record their work in exercise books, other forms of assessing children's learning could be used which would enable teachers and others to see children's progress. These could be, for instance, posters expressing the children's ideas either as individuals or groups, computer programs and presentations, video films or recorded discussions, all depicting aspects of their understanding of the topic they study.

Whilst the curriculum is so content-oriented and requires knowledge of this content to be tested at frequent intervals, the scope for other forms of recording lesson material and individual understanding will remain limited. The notes the children make in their exercise books when they copy from the board could reveal areas where their understanding is incomplete, rather than incorrectly copied, the assumption most likely to be made.

The study teacher used worksheets from a published scheme of work. These were given to the children without any alteration. Producing and adapting worksheets and illustrations from published texts suggests that teachers are endeavouring to create material appropriate for their classes at the time. A teacher's knowledge of the children they are teaching, in terms of their abilities and learning preferences, allows them to consider the most appropriate materials to use to ensure engagement by the maximum number of children. If published materials are regarded as inappropriate on whatever basis, for example, difficult because it is felt that there is too much written text or the accompanying diagrams are too complicated, then it is likely to be beneficial for the children that materials are produced specifically for their needs. On the other hand, as has been noted above, alteration of materials may change their content. Unless there is an awareness of the initial content and the potential effect on that content of changes, there is scope for producing materials that confuse or fail to facilitate conceptual engagement or challenge, limiting their potential for the construction of valid knowledge.

In this respect it would be useful if teachers were able to analyse the content of representative materials they opt to use, particularly if they then adapt the materials to produce worksheets. This again raises the questions about the reasons teachers feel the need to 'rework' the published materials, suggesting an inadequacy of format and content, which needs addressing by the publishers.

7.3.4 Concrete models as representations

The study teacher used a variety of different types of representation. Most were two-dimensional. The physical models made by the children to illustrate the distance between and difference in size of the planets gave no indication of the spherical nature of the bodies involved, other than showing them as a circle. The assumption appears to have been made consciously or otherwise that the children were aware of the spherical nature of the bodies and were able to translate this knowledge to the different formats of presentation, such as a rectangular name label or a card circle. Given that research shows that children initially hold a flat Earth concept (Baxter 1989, Vosniadou and Brewer 1992) it may be reasonable to assume that when confronted with two-dimensional circles representing the other planets, the flat Earth notion is transferred, at least for young children, to these bodies.

Most adults are aware that the bodies in the Solar System are spherical and it is possible that teachers fail to remember or recognise the stages of conceptual development undertaken to reach that point, but which the children may still be undergoing. The fact that the study teacher made no attempt to ascertain the children's ideas about the shape of the Earth or other bodies in the Solar System may be because these facts had been taught and tested in lower years and were therefore felt to be secure. The children had encountered the notion of a sphere in there maths lessons in Year 2 (ages 7-8 years) Though this may be the case it is an example of the manner in which teachers interpret and control the curriculum they teach, subordinating ideas to the facts to be learned (Sizmur and Ashby 1997). This raises the issue of what teachers feel learning in science actually entails.

7.4 The importance of science education

Learning in science is not just learning lists of facts about natural phenomena, though in some instances it may appear to be just that (Heywood 2001). Whilst there is no doubt that some facts are important to developing a deeper understanding of many aspects of physical phenomena, learning them by rote is not necessarily the most productive manner in which to acquire this knowledge (Mayer 2002). If science is regarded as including understanding the nature of science and its procedures, and scientific literacy as understanding the manner in which scientists use these aspects to investigate their observations, then children engaged in a similar process through their lessons will be given the facilities for engagement in and understanding of the natural world in which they exist. Leach and Paulsen (1999) identified this aspect of science education as:

> Students need[ing] some meta-understanding of the
> nature of scientific content knowledge in order
> to be able to interact with it when encountered
> in the media or professional settings.... p134/5

The manner in which this is achieved is the subject of ongoing debates, but the need for a scientifically literate society is becoming widely accepted in view of the global changes that are affecting the world. Individuals' understanding of their contribution to these changes will be dependent on their level of understanding of the scientific claims made to explain them.

The ability to assess new information in the light of scientifically accurate current knowledge requires the ability to think clearly and logically, integrating new facts with existing knowledge. Ensuring a scientifically literate population relies on effective teaching from the start and includes all agencies with which children interact schools, media and parents.

The changes that have been made to the National Curriculum for Science in the years since its inception have reduced the importance of some of the aspects of the Earth in Space topic. One of the reasons for this could be the difficulties experienced by primary school teachers in understanding the relatively complex ideas required for a complete understanding of the behaviours and mechanisms operative in such phenomena. Another could be the relevance for children as night skies are generally so light polluted that the stars and planets are not easily visible from the Earth in many places. Seasonal changes have less impact nowadays due to urbanisation and improved living conditions so few changes to daily behaviours are needed. The phases of the Moon are probably the most observable aspect of the topic. On the other hand, knowledge about the world in which we live extends to the reasons for day and night, the manner in which the Moon apparently changes shape over a recognisable period of time, the Earth's interaction with the other bodies in the Solar System and the importance of the Sun as our energy source.

The Solar System is said to be one of the most popular topics of study in primary science (along with dinosaurs) (Sizmur and Ashby 1997) but the actual content of the curriculum topic bears little relationship to the prospect of aliens and space ships which may be part of the appeal. Knowledge of the organisation, structure and inter-relationships of bodies in the Solar System will provide children with the underlying understanding with which to interpret their world in an informed manner.

7.5 Developments in understandings of knowledge construction in primary science

The present emphasis on the construction of knowledge by learners across the curriculum and in science education in particular, has led to the notion of starting 'where the child is at', though in reality this is difficult to achieve in many classrooms for a number of reasons. In part this is due to the structured nature of the current curriculum which is to an extent at odds with the current notions of constructivist theories.

Science education has been at the forefront of developing ideas about effective teaching and learning for over a hundred years and particularly in the last twenty. It is an exciting time for teachers and learners as research deepens our understanding of the manner in which developing theories of teaching and learning actually operate in the classroom and contribute to the construction of knowledge of the world in which we live. Representational materials play an important role in science education. Increasing teachers' understanding and awareness of the use they make of visual materials in primary science classrooms and the impact of these materials on the construction of knowledge by pupils, will contribute to the continuing development of effective science education.

Appendices

Appendix I

Scientific Explanations

These are the scientifically agreed explanations of aspects of the topic in the Earth in Space for the information of readers.

Seasonal change

The Sun is the star at the centre of our Solar System. It is a body of glowing gases with a surface temperature of 5,500°C. The energy is produced by nuclear reactions in the core. The core of the Sun, approximately 2% of its total volume, consists mainly of hydrogen. The core is very dense, 60% of the total mass.

The temperature of the core is approximately 15 million °C. This huge temperature and pressure in the core cause the atoms of hydrogen to collapse into sub-atomic particles, electrons and nuclei. This releases heat energy and gamma rays. The hydrogen sub-atomic particles collide, fuse and become converted into helium through nuclear fusion. This reaction also releases energy. Gamma rays travel to the Sun's surface over a period of thousands of years. As they pass through the clouds of helium, they lose energy as they collide with the gas particles. These collisions result in photons. Photons consist of many gamma ray particles and have a longer wavelength. At the surface of the Sun, the photons are released as visible light rays, which travel unimpeded, and therefore in a straight line, through the empty void of space between the Sun and Earth (and the other planets and bodies in the Solar System). Heat energy is also produced in the core as a result of the atomic activity. It travels through the gases surrounding the Sun's core until it reaches the surface, from where it is radiated into space. The radiated heat and light energy travels through the Earth's atmosphere and strikes the surface. Some of the energy is dissipated by the atmosphere, this percentage dissipated depends on the atmospheric conditions, for example, a large amount of cloud cover will increase the amount of dissipation, as would high levels of atmospheric pollutants.

The Earth orbits the Sun in an elliptical planar orbit. At the same time the Earth revolves on its axis. The period (the time taken for one orbit) of the Earth's orbit around the Sun is 365¼ days, an Earth year. The period of the rotation of the Earth is 24 hours, an Earth day. The Sun's energy strikes every part of the Earth facing the Sun. The amount of energy striking the Earth surface at any time remains more or less constant, 1.37kW per square metre, (the solar constant) changed only by the prevailing atmospheric conditions.

An imaginary line through the centre of the Earth, the axis, is tilted at an angle of 23.45° away from the perpendicular of the ecliptic (the plane of the Earth's orbit around the Sun). The angle of tilt remains constant throughout the orbit and is not affected by the Earth's rotation.

The Earth is approximately spherical in shape with a diameter of 12,777 km at the equator. Because of the Earth's approximately spherical shape (it actually bulges slightly at the equator, due to the forces involved in the rotation and orbit) the surface is curved. Energy from the Sun hitting the Earth's surface at points towards the extremes of the hemispheres, does so at an oblique angle, compared to the Equator, where the angle is perpendicular. As light (and heat energy) travels in straight lines, where the Sun's energy hits the Earth at an oblique angle the energy is dissipated over a greater area, therefore, the intensity of the heat and light per unit area on the surface is less than where the angle of incidence is perpendicular.

The angle of tilt remains relatively constant during the Earth's orbit of the Sun, so, the angle of incidence of the Sun's energy towards the poles changes as the orbit progresses. At some points in the orbit the angle of tilt will be inclined towards the Sun and at others it will be inclined away. The degree of inclination determines the angle of incidence and therefore the amount of energy striking the Earth.

As the Earth's orbit around the Sun is slightly elliptical, with the Sun at one of the two foci of the ellipse, the distance between the Sun and Earth varies. The nearest point of the Earth's orbit of the Sun (perihelion) is 147 million kilometres and the furthest (aphelion) 152 million kilometres. The perihelion occurs during the British winter and the aphelion occurs during the British summer.

The apparent height of the Sun in the sky is also as a result of the angle of inclination of the Earth. Britain's geographic position, relatively near the North Pole, affects the position from which the Sun can be observed. As the tilt is inclined away from the Sun in winter, the Sun appears to be nearer the horizon. This also has the effect of shorter daylight hours as the Britain spends more of its time in the dark part of the Earth's daily rotation. In the summer months, when the Earth's tilt is inclined towards the Sun, the northern hemisphere experiences longer periods of daylight and the Sun appears higher in the sky. The Sun sets and rises due West and East respectively on the equinoxes, 21st March and 21st September, moving slightly east as the year progresses, until the winter Sun sets east of west.

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The Phases of the Moon

The Moon emits no light of its own. Its surface consists of a thick layer of grey dust and it has no atmosphere. Light from the Sun is reflected off the dusty surface, allowing the Moon to be seen from Earth. When the full Moon is visible in the sky it is possible to see surface features as there is no atmosphere to obscure our view.

The rotation and orbit of the Moon around the Earth are both approximately 29.5 days. Therefore the Moon always presents the same face to the Earth. The orbital path of the Moon around the Earth is angled at 5° to the Earth's ecliptic and is slightly elliptical (apogee 406,700 km. and perigee 448,700 km.) The ecliptic is the plane of the Earth's orbit around the Sun.

Half of the Moon's surface is always illuminated by the Sun. The fact that we do not see the whole of the illuminated surface is due to the fact that the Moon's orbit means that its position in the sky changes in relation to our position on Earth. Though we could see the whole Moon, limitations of our eyesight to the visible spectrum mean that we see different portions throughout its orbit. The proportion of the Moon that is visible from Earth changes in a regular pattern. These are the phases of the Moon.

In certain circumstances it is possible to see faintly, the unlit part of the Moon, due to light reflecting off the Earth's surface, faintly illuminating the whole Moon.
The Moon rises in the sky approximately 50 minutes later each day due to the discrepancy between the lunar month and the calendar month, but the pattern of the phases remains the same.

The height of the Moon in the sky appears to change due to the tilt of the Earth and angle of the Moon's orbit around the Earth, in the same way that the position of the Sun appears to change. This angle means that it does not pass directly in front of the Sun every month, the eclipse position, when the Moon is in the Earth's shadow which occurs every 18 years.

Appendix II

Data collection projects – all school names are pseudonyms

Date	School/place	Topic	Comment
1995 Jan	St May's Y5 - 15	Drawings of what is in the Solar System – 31 drawings pre and post teaching	None used for this study – research techniques developed
1996 24th March	St May's Y3 - 15 Y4 - 13 Y5 - 15	Investigation into ideas about scale –'Draw me something that is a bit bigger than you and a bit smaller than you'. Same Same	None used for this study – research techniques developed
1996 – 25th March	St May's Y5 - 16	Children talking about the Solar System in relation to the orreries we had used in class, after teaching the topic. Divided into 3 groups of 2 x 5 and 1 x 6.	Papers written and published in the Bulmershe Papers (1997) and PSR Nos. 50 (1997) and 53 (1998) ASE conference. Informed this study
1998	Parsonage Street My class Y5 - 34 Mixed GW's Class: Y7 - 36 Mixed	Questions about how day and night occur. Drawings of the Earth, Moon and Sun Drawing the Solar System before (7.1.98) and after (25.2.98) teaching	Article published PSR 59 (1999)
1998 – June/July	Saint Peters Y2 - 28 Mixed	List of bigger and smaller (Y2)	None used for this study – research techniques developed
1999 – Sept	Harries Y4 - 6 Mixed	Children looking at representations of the season post a teaching session and explaining their ideas about how the seasons worked – also drawings	Article published PSTT 16 (2001) Tapes of conversations – not transcribed
2000-April	Dome 5 subjects age range 10 -18years	Interviews with children (5) after a visit to the Body Zone of the Millennium Dome.	Papers presented at Winchester (King Alfred's) and BERA students 2001. Tapes (transcribed) and scans of pictures taken of the Dome exhibit.
2000 - 03	St. Martin's Y5 -28 Mixed	BPRS project looking at learning from computers and books. Test devised and given pre and post teaching topic (Earth, Sun and Moon)	Test developed which has been used in Parsonage Street and Southfield. It was piloted in Southfield. Videos of the children working with books and computers. Videos analysed to see the amount of engagement with each media.
2000	Southfield Y4 -22	Questions about the Earth, Moon and Sun and seasons.	Continuation of project at St. May's.

Date	School/place	Topic	Comment
2000	Southfield Y4 - 44 Y5 - 22	Pilot of test (11/02) 3 classes 2xY4 & 1xY5 results.	Results of the test analysed and those questions consistently unanswered or wrongly answered by the children removed from the test. Test covers seasons and the phases of the Moon and some general Solar System knowledge.
2001	Robinswood Y4 - 24 Mixed	Asking questions about the seasons and the phases of the Moon.	Article published in School Science Review: Children's understanding of scale – the use of microscopes. 82(301)p27-33
2002-June	Robinswood Y6 - 32 Mixed	Trialling representations for fieldwork in Parsonage Street + concept maps and cartoons of the seasons and the moon phases (Y6)	Tapes poor – transcripts only partial – representations selected immediately after the session from memory of what the children had said and selected.
2002-Feb	Parsonage Street Heywood Gallery Y5 - 23 Mixed	Accompanied Caroline's class to the Heywood Gallery to view a Paul Klee exhibition. Conversations with the children recorded.	Tapes of children talking as they go round the exhibition - Not transcribed – post cards of pictures viewed. I thought this might be useful as the children were looking at unconstructed art work
2002 May/June	Parsonage Street Y5 - 23 Mixed	Interviewing children with representations from books (decided by the children from Robinswood) after the topic was taught.	Interviews with 6 groups of children recorded after the topic was taught. Interview with the teacher. Used concept maps with some of the children. Also used concept cartoons.
2003 March -June	Southfield Y5 - 22	Video of a whole series of science lessons + interviews with children and study teacher 2 interviews (4 children) – one before teaching the topic one after.	Interviews with a group of 4 children, before and after teaching topic. Also interviews with 5 groups of children after the topic. Interview with the teacher. Used concept cartoons and book pictures.
On going	Various sources	Analysis of a variety of book representations of the seasons and the Earth in Space.	Extensive collection of CD-ROM, encyclopaedia and text book examples.
2004 – March - June	Southfield – Y5 - 22	Copies of two of the case study children's exercise books. Copies of the poster produced by children from their computer research and a 'fan' model.	Additional material for thesis.

Appendix III

Questions for Interviews with children

What can you tell me about the seasons?

Do you know how they happen?

What do you think about these pages?

Do you think they would help people understand about how the seasons happen?

These are the questions that were asked at all interviews with children. Depending on their replies a variety of prompts were used.

Prompts

Can you explain to me?

Why do you think that?

How do you know that?

Which do you think is the best explanation?

All interviews ended

Is there anything else you would like to say?

Appendix IV

Example Transcription showing gesture and equipment notation

		Tape 4		
No.	**Sp kr**	**Talk**	**Gesture**	**Equip ment**
1.49	T	Right, ssh, are we ready? Ssh! Come on *(indistinct) back three weeks, which is quite a long time ago. Back before the Easter holidays, we started talking about the Solar System. And I can see M's been busy. That will be very useful for what we're doing today M. Is it pictures of different planets?	*claps	
	M	Yes		
2.26	T	It will be useful on Friday actually so try and remember to bring it on Friday. So, we started, just a minute, let me finish my turn. We started talking about the Solar System and learning a little bit about the Solar System and we've made, most people I think finished making, a little model. Oh! That one's not finished, I'll find one that is finished. Oh!	Picks up string model	
	CH	We haven't finished any of ours.		
	T	Yes some people finished.		
	CH	I did		
3.02	T	Now the last thing we made some little models of (..6..) the distances the planets are from each other. OK, now I know some people haven't finished and we need to have a lunchtime session for those people. So, we've had a little think about how for the planets are from each other, so we've got those four, can anybody remember what the first four planets together are called? Er no, we'll go back a bit. Who can give the names of the first four planets? Chloe		
	C	Rocky planets		
	T	They are the rocky planets. What are their names, in order?		
	C	Mars?		
	T	The other in one		
	C	Oh, Mercury (yes), Venus (yes), Earth (yes) Mars		

		T	Right, so the first four are Mercury, Venus, Earth and Mars, the rocky planets and they are pretty close to the Sun* Then we have quite a big gap, then we've got **1, 2, 3, 4 the next four quite spread out. Anybody know what they're called? M, you know this. So, we've Mercury, Venus, Earth, Mars. What comes next?	*holds disc at eye level horizontal peering at chatting child (check who) **counts down each planet.	
		M	Jupiter		
		T	Pardon, say it a bit louder.		
4.02		M	*Jupiter, Saturn, Uranus	*counts then down the string as M says them	
		T	And…		
		M	Neptune		
		T	Thank you. What're they called? Anybody remember what they're called altogether? Right, the first four* are called the rocky planets, what are the next four called? **Anybody remember the name***. What have they**** got lots of around them?*****	*small circular gesture with both hands **swaps disc to other hand ***pulls face ****circles arm *****points at Je who has hand up	
		J	Gas		
		T	Yes, they're gas giants*. OK and what's the little one at the end** there Ana?	*Snatches hand back to self and fingers down string again. **holds up end of string with label (Pluto) on.	
		A	Pluto		
		T	Yes, little Pluto at the end there right, yes, exactly and if you haven't finished, we'll have a lunch time session to finish those.*	*folds up string	
4.36 4.45			Now what we're going to on to think about, having* thought about the distances of planets from each other what I thought we'd go on to think about, if** Cha's thank you$ listening is the different sizes*** of the planets. OK 'cos not only are they different distances from the Sun, but they are different sizes^ #Which one do you think is the biggest@ Re?	* turns to replace string model in the box on table by board. **rubs nose with rh $forced smile in C direction ***emphasised and draws circle with both hands at waist height then clasps	

			hands at waist. ^open palms moving hands jots apart #both hands on cheeks slides them to month @holds in front	
	R	Jupiter		
	T	It is, I'll* tell you, mind boggling information, ** it is 142,600 kilometres across that is very, very large@ OK which one's the smallest one, which$ one's the smallest Lou?	*picks up sheet **reads from sheet @looks at sheet $scanning class	
	L	Pluto		
5.19	T	Pluto, little old Pluto is only, and this isn't* very big really 2,287 km across, now 2000 km is about from here to (interruption) Now 2000km is only from, now what's 2000km away round the other side of the world somewhere Australia	*looking at sheet Puts down paper Picks it up Reads paper and rubs lips	
	GM	No, the world's not that big.		
	T	It is the world's 1200km in diameter, 2000 is		
	GM	It's about 1 ½ times round the Earth then		
	T	It is actually, yes, but it not as big as … 2000km. Well, let's just think … from here to Scotland is about 500km, yeah, from here to Scotland, so from Northwood to Edinburgh lets say is 500km so if you drove from here to Scotland and back again and back again and about.		
6.45		Half way back again, it would be the *distance all the way across Pluto, so it not absolutely ginormous. Its about 4 ½** times the distance to Scotland.	* draws flat line in front of self ** moves LH back and f 4 times	
	E	The distance to the south of France		
	T	Yes, probably		
	E	Or to Italy		
	T	Yes, or to Italy something like that – so its not that big really, Pluto. If you think about it. Now*. Yes, Cha?	*put sheet down	
	C	Is Jupiter bigger than Earth?		
7.22	T	Yes, we're going to do a model* to show that. Now explain what we're going to do. We could, we could, Louise just in	*LH draws semi-circle	

		our science books draw a table and write** down how big the planets are, but@ that's a bit boring, so what thought we'd do is a model# of how big the planets.	**waves LH as if writing @flap hand in front of mouth #draws full circle – both hands	
	CH	Oh, yes		
7.32		Let me explain what we're going to do it*. What we're going to do is, here's** one I started earlier. What we're going to do is, how many planets are there altogether.	* clasps hands **reaches for A3 piece of card	
	CH	9		
	T	9 planets so, I haven't drawn them all out yet I've only drawn 6 of them on this sheet. So, everybody is going to have a piece of card. The first thing you're going to do is what? * Write your name on it.	*holds card sheet landscape to rh side	
8.16	T	Well done, Rosi, write your name on the back, cos we won't* finish this today so write your name on the back, and then I'm going to tell** you how big to draw the circles for each planet, so that they are the right size compared with each other how Cha, you were asking me if Jupiter was bigger than …	*flat hand wave **starts pointing finger to enunciate words	
	C	Earth		
	T	Than Earth right now, the model we're going to do, this is* the size for Jupiter the biggest planet and that** is the size of Earth. So is Jupiter bigger than the Earth?	*draws round outline with forefinger of LH **points to bottom of card	
	CH	Yes		
	T	I think so		
	?	And so's Saturn		
	T	Now, yes		
	E	Is the Sun bigger than Jupiter?		
8.52	T	The Sun's much bigger than Jupiter. What I think we'll do, let me explain** what we'll do with these when we've done them, so what we're going to do is is we're going to do all 9 planets. Now the little one's we're going to have to do in a slightly different way because	Nods head as speaks **flat hand wave	

10.19		they're going to be too* small for what we actually want to do with them all in the end. So, we're going to colour them all in nicely and write their names on them and then we're going to put them one on top of the each other, in order of size, so Saturn's going to go on top of Jupiter. Neptune on top of Saturn, then Uranus the Earth then Venus, then the other ones I think we might have to draw and cut out rather than *drawing* them with a compass. And then you know those paper fasteners that you put through with little legs, what I thought we could do is put a paper fastener through so that you've got used out on the field@ so that you know what colours you need# to colour them, alright, so today's job is just a minute, today's job is going to be is to get the circle's** drawn the right sizes how for the first, I managed 6 of the planets, draw$ 6 of the planets and I'll tell you how big to do them, using a compass if you've got one.	*finger and thumb tog (LH) points to each planet makes small drawing movement puts card down @draws large circle with both hands #draws another large circle and one smaller holds up LH with 4 finger pointing in the air. **flat RH up and down over card on table. $picks up compass box, takes one out and holds it up.	
	CH	Yes		
	T	Ok, now the first 6 planets I think we are able to do with the compass, the other 3* are too little …	Still holding compass in the air 'wags' it on every syllable. *puts basket down	
10.56		10.56-14.41 using a compass, handing out paper for ch to start		
16.41 9.28		Now what we need, ssssssh, are you listening? What need to end up with today is a sheet of card with 9 circles on, of the correct size, Now sizes, I'm going to write them up largest to smallest, largest to smallest. Like a planet fan	Picks up crib sheet	
	G	Oh, that's clever!		
	T	That's good isn't it? don't you think that'd be quite nice, we'll give it a go and see how it works, so we're going to make a planet fan, now. Yes, Gina, what do you want?		

	G	You know when you told us to colour [T yes] in … can we use felt pens?		
	E	It wouldn't work out that nice 'cos they're too big a space		
↓ 17.00	T	*I think we're going to use coloured pens and what I've actually got, if you haven't got your own, **whoops, if you haven't got your own, coloured pencils, luckily M W came and restocked my pencils this morning@ so I've got a whole, big, huge tub, but we won't get onto that, that'll be Friday's job I think, $ colouring in. Now we'll get the, the big, ssh, ssh, I think M^ S's got them at the moment, the big*** circles we. So, lets have a bit of a guessing game as to what order they will go in. So biggest one. We've already discussed**** what that was, Cha, what was the biggest one – do you remember?	*scratches ear and pulls a face **puts down card (back to class) and picks up tub of pencils. @faces class with tub under left arm and takes the lid off and leans tub towards class. $ puts lid back on ^looks left to right ***puts pencils down ****wags left hand	
	C	Jupiter		
↓	T	Jupiter is the largest planet, you don't need to write this down. Jupiter is the largest planet, put your* hand down and for Jupiter you're going to need a circle with a radius, we're going to put the radius** up here not that diameters so this is what you set your compass to get the right size circle radius of 14.3 cm alright, so remember millimetres. It's going to be 14 cm and 3 mms OK, if you're not happy about cm and mm ask for help or ask the person next to you, one in each pair will be alright with cm and mm. Al (who has hand up) is this about Jupiter?	Looks at sheet and turns to board Writes Jupiter *wafts hand at child with hand up **writes radius on board, underlines holds finger and thumb small distance apart. Uses right hand over 14 and then 3.	
17.55	A	No, it's just that I don't think my compass will go that big.		
↓	T	I think it will because these *ones do and they look the same size to me.	*walks over and picks up class compass	
	A	Can I borrow one please?		
	T	Yes, I'll give them out in a minute. Can we just get the right sizes on the board first? Right, sssh, Ok, ere, er Jae* no, can you put your compass down for a minute? I don't want anybody fiddling,	*shakes head at Jae and wobbles hand at hip level.	

		we've got a thinking exercise here. Right ? Cl which do you think is the next biggest?		
	Cl eo	Saturn		
	T	Yeah, Saturn* is the next biggest and in our model that we're making, Saturn is 12, I'll put in the .0 (zero) in to be accurate, but 12 cm radius, 12 cm radius, right who can think what the next will be? Rema?	*writes Saturn on board	
	R	Neptune		
	T	Have you got this* in front of you? Correct.	*referring to crib sheet	
19	R	No, but I remember you saying		
	T	Neptune is the next one, that is another easy because that is 5cm radius so not all of them have got mm to worry about here. Next one M, which one's the next biggest?		
	M	[indistinct]	T has thumb/finger to mouth as waits for M to deliberate	
	T	Which one sort of goes with Neptune I always think of these two as sort of going together		
	M	What are they next to each other? ... Uranus		
19.47	T	Uranus and ssh Uranus is, it's nearly the same size lets just get this there is only 1mm difference in the radius according to our model, so you have to be careful when you draw those two because we don't want them to end up the same size. We do want them to look ..@.. we do want them to look different/a little bit different. Right, Cleo, next one please.	Writes Uranus on the board Finger in the air (LH forefinger) @glares at someone	
	C	Erm, I don't know it.	Hand on chin	
	T	I'll give you a clue, you're sitting on it.		
	C	Oh, earth		
20.47	T	Yes, and the next biggest is Earth and there's a big* drop now we go from 4.9 radius to 1.3. Lets just stop there and have a look**, a sort of recap, so here we go That's the size of Jupiter, there's Saturn and Neptune and Uranus quite similar in size and then quite a big drop down to Earth@. Ok, so who knows the next one? Go on then? Venus# that's next one, I've just shown you. That's	*points at CH **picks up piece of card circles around the drawing of J points to Sat and Ur and Nep	

		good fair enough. And Venus is going to be not very different from Earth, so again you've got to be very careful how you draw these Charlie, thank you, 1.2cm. Now that's the first, 1, 2 …^ that's the first 6. Those are the ones that I think you can draw accurately with a compass$. Ok, so lets make a start on those, then we'll worry about, no lets write down the others. Now the other 3, Jane, you*** shouldn't have started anything yet, thank you. Now the other 3, I think you're going to have to draw … free% hand or I wonder if we could get some coins out see how big the 1p coins are.	@puts sheet down #writes Venus ^counts down the list on the board $hand down in slicing movement emphasis/word ***shakes head %makes small circle movements in front of face	
	?	5p		
	Je	I've got a 5p coin in my purse		
22.37	T	That's a good idea, right the sizes we're going to need are, Mars* which is the next smallest after Venus, now I'm going to write the diameter for these, we're not going to use the compass for these, we need to know the total distance across, for these ones, so Mars is 1.4cm altogether, so I wonder if that's the size of a 1p? No!	*writes Mars on board Writes diameter above Mars	
41.56	P	Is any body colouring in Jupiter at the moment?	Wall poster	
	?	I'm colouring, I'm on Uranus		
	T	Ssh, can you listen please, ssh listen, listen ah. One of the most famous things about Jupiter is that it has this big storm* which is called the red spot so I think everybody needs make sure that they to do this big storm which has been raging for phaw, millions of years on Jupiter so make sure that you get the red spot in so you need an area that's like an oval a red oval**	*indicates with forefinger RH on poster **indicating a small oval with LH in front of face – hand still on poster.	
42.58		CH carry on	Finishes putting up poster	
1.09		Starts to close lesson		

Appendix V

Coding system and sources

Sign	Meaning	Sources
(.)	Noticeable pause – less than 0.2 sec	Duranti 1997 Jefferson 2002 Du Bois 1991
(…)	Untimed pause	Deacon et al 1999 Du Bois 1991 Jefferson 2002
(4)	Timed pause	Deacon et al 1999 Duranti 1997 Du Bois 1991 Jefferson 2002
( )	Indecipherable utterance	Deacon et al 1999 Du Bois 1991 Jefferson 2002
(word)	Best guess of utterance	Duranti 1997 Atkinson and Heritage 1984
<u>word</u>	Stressed word	Deacon et al 1999 Jefferson 2002
WORD	Highly stressed word	Deacon et al 1999 Jefferson 2002
Wo:::rd	Stretched word	Deacon et al 1999 Jefferson 2002
°word°	Whispered word	Deacon et al 1999 Du Bois 1991 Jefferson 2002
((*smiles*))	Non-verbal contribution	Deacon et al 1999 Duranti 1997 Jefferson 2002

Appendix VI

Selection of teacher interview - coded transcript.

Numbers in brackets refer to tape counter.

85 I: Scientific background you feel is quite is obviously erm, erm is obviously quite important, especially with things like the seasons?

86 T: I think its important with <u>any</u> science because I think you have to know much more than the girls in order to be able to see , what their, where they're coming from in terms of <u>their</u> understanding and b, be confident enough to put them right, if you see what I mean (...) 'cos quite often, you, <u>you think</u> they understand something when in <u>fact</u> by things they say and maybe the things they write and draw you're completely wrong and they <u>haven't</u> actually understood, so if you've got much greater scientific knowledge than they have, you can immediately see where their thinking has led them and make them back track and go down the right path, whereas somebody like Sam or Jim can't do that.

87 I: Do you think that the types of representations that you use actually enhance

88 T: (   )

89 I: Pardon

90 T: Get back to them

91 I: No, no, no, if, it's actually very important nobody's actually said that before.

92 T: Well the more I, I mean I've been doing this, is my third, it more or less my third year, its my second year actually in this job, but my 3rd year in teaching science at this level, and its something that <u>hit</u> me straight away was how important it actually is and I don't think that people realise how important it is that the person teaching, probably any subject, but from my point of view science, <u>has to be</u>, has to be ABSOLUTELY confident in what they're doing and their knowledge. 'Cos if you start leading them

down the wrong path, 'cos you don't know what you're on about they're going to be just, phut, forget it, they're going to be so::::: confused.

93 I: that you build on their misunderstandings? (110)

94 T: Yes, you've got to be able to say, hang on NO, you know, STOP you're WRONG lets go back a step and if you're, you're a scientist then you can obviously do that, but if you're not you're going to flap around just as much as they are

96 I: would you necessarily spot where they've made mistakes?

97 T: if you weren't a scientist no I don't think you, cos I don't think that you, you wouldn't have the deeper (...) knowledge. Having gone through it a couple of times I now know the danger points, if you like, where I can see that 4 or 5 of them are going to go off on the wrong track, so I can make sure that that bit is dead solid before we go on to the next bit.

Appendix VII

Transcript excerpt **Southfield – children's interview 1**

Participants: J
B
P
R
I = Interviewer

Key to coding

Phrase = observable changes – e.g. flowers in spring

Phrase = naming of seasons

Phrase = weather references changes in, rainy, foggy in winter

Phrase = weather references – temperature differences, cold in winter

Phrase = light references, darker in winter

Phrase = behaviour - positional

Phrase = behavioural orbits.

Numbers in brackets refer to tape counter.

1. I: One of the things I want to talk to you about is the seasons. What can you tell me about the seasons? Do you know how the seasons happen?

2. Chorus: Yes

3. I: You're all nodding, do you erm can you tell me, some ideas

4. R: Erm well there are 4 seasons, winter, spring summer and autumn. And winter is a cold month and summer is hot and spring is when all the flowers start to come out, autumns when leaves start to die and wither
(20)
5. I: ok anything else?

6. J: well it happens like in the course of during the year, so that they like overlap so they start in the middle of and they end in the middle of another month. And like winter is in between the end of one year and the start of another year. Then spring comes then summer and then autumn and then back to winter again

7. R: if that, if when your going through the seasons you won't actually find that much of a drastic change and most of the time you will sort of gradually say its from summer

to autumn, you'll gradually see everything like changing to a different thing, not extremely fast

8. P: I'm not sure but every year there's not a set date for the seasons to change, they'll always change on different dates

9. R: there more or less same

10. J: yes more or less around the same time

11. P: more or less but not exactly the same day

12. A: you never know

13. R: yeah, like in summer there's more light, you get more light so erm, like erm at night it stays till may be about 10 or 11 o'clock and it's still light and it gradually starts getting darker, but in winter around 5 o'clock it's dark

14. P: about 4 actually

15. R: yeah 4, 5. I'm not sure but if it gets lighter in the summer it kind of must mean that the Sun is nearer to the Earth then, than it is in another part of the world where they might have different seasons, I don't know

16. everyone speaking at once – indistinct

17. P: the Sun, the Earth rotates the Sun and when ever the Earth comes nearer to the Sun, it's nearer

18. J: well it stays in the same circle

19. P: yeah it stays in the same circle but I mean when ever the Sun comes near the Earth, so into England is well (sighs)

20. All at once

21. R: the Earth rotates round the Sun

22. all at once

23. J: all of the planets go round

24. R: yeah

25. J: all of them orbit the Sun

26. R: what happens is the Earth actually turns around while it is going round the Sun and it takes a whole year, so when our side of the Earth is erm nearer to the Sun you have summer and the other side have winter, but then when

27. J: it does change

28. R: our side it changes kind of like that I think

29. I: what takes the year?

30. P: the Earth to go round the Sun

31. B: no the Earth rotates round in one day but it takes one year for it go round the Sun

32. J: round the Sun

33. Indistinct ( )

34. J: I said that

35. R: that's what I meant

36. I: does anybody know anything else about the seasons? You've mentioned the light, anything else?

37. B: sort of like maybe like in the summer it means like different things can sort of like happen different like activities and stuff

38. R: you can do different things depending on the weather

39. B: and it might

40. I: on the weather?

41. R: and you know when the change cos they um I'm guessing here now in spring blossom comes out or something like that

42. B: and as well there's daffodils

43. P: daffodils in spring

44. B: and in winter in might rain a lot or something and different events like floods or something might be able to happen

45. J: yeah

46. I: what changes the weather?

47. R: the seasons cos, change the weather, depending on what season cos you

48. P: gosh J you're really clever at maths as well

49. J: do you mind

50. P: well you are!

51. R: oh I know is it during the spring and autumn the Earth doesn't lean towards so much the Sun and in the summer it leans more to the Sun

52. B: oh yeah

53. J: so you get more heat

54. all tog

55. I: sorry go on

56. B: there's something about like it leans towards the Sun

57. P: the Earth is actually leaning towards the Sun, so in the winter it may be goes back or something

58. R: its to do with the northern and southern hemisphere or something

59. J: yeah, cos when the northern, when it's tilted the northern hemisphere goes like that (angles her palm at 45 degrees) towards the Sun where it is summer, when the southern hemisphere is tilted they get the summer

60. I: ok did you know the Earth was tilted before you looked at that?

61. chorus of no

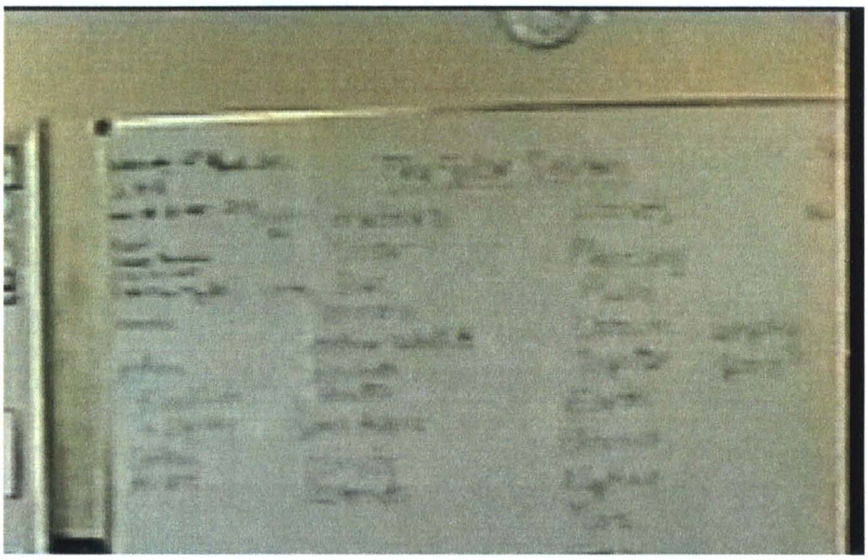
62. J: I think my dad might have told me it somewhere but I don't

763. A: yes I've read it somewhere

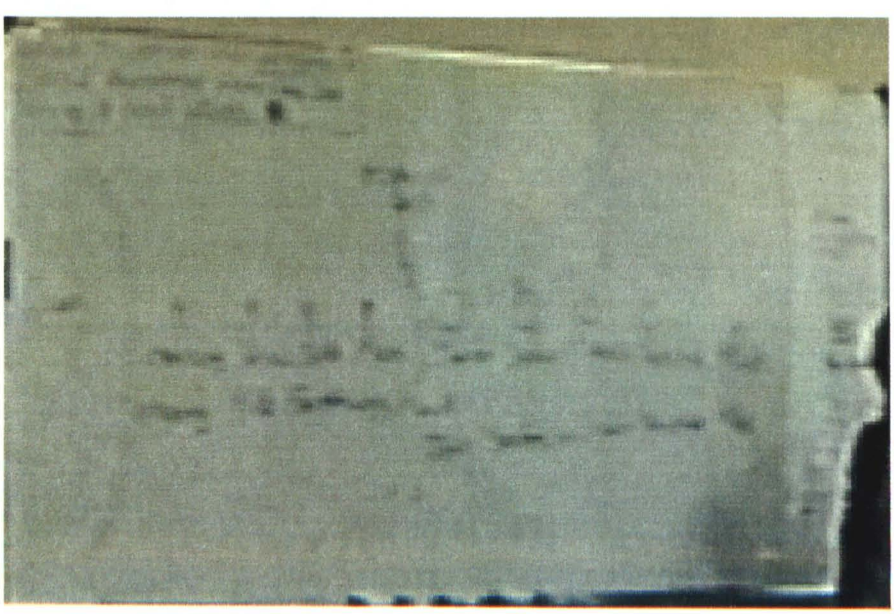
Appendix VIII

Board diagrams

The figures presented in this appendix are stills taken from the video recordings the lessons. They are of poor quality as the video camera, the only one available for extended loan, was elderly. The video recordings were very clear to watch on the screen but this did not transfer to the stills. The board diagrams are presented here to give an impression of the diagrammatic material the teacher drew for the children. Photographs were not taken as this was considered too intrusive to the lessons. The diagrams were not re-drawn as this would potentially alter their construction. Analysis was undertaken directly from the television screen.

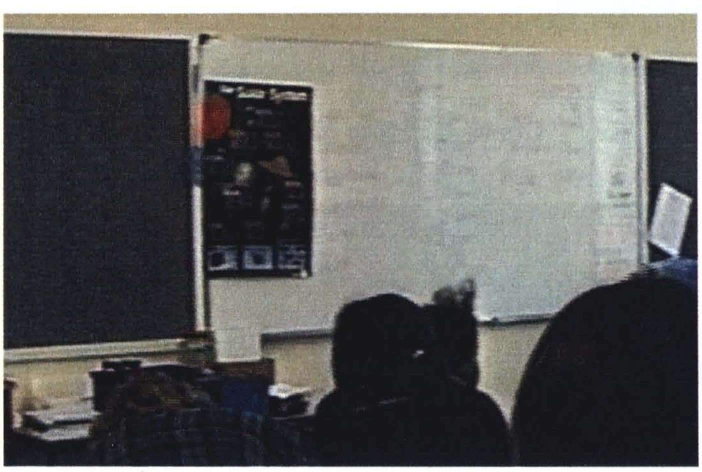


The board diagram of the contents of the Solar System – lesson 1



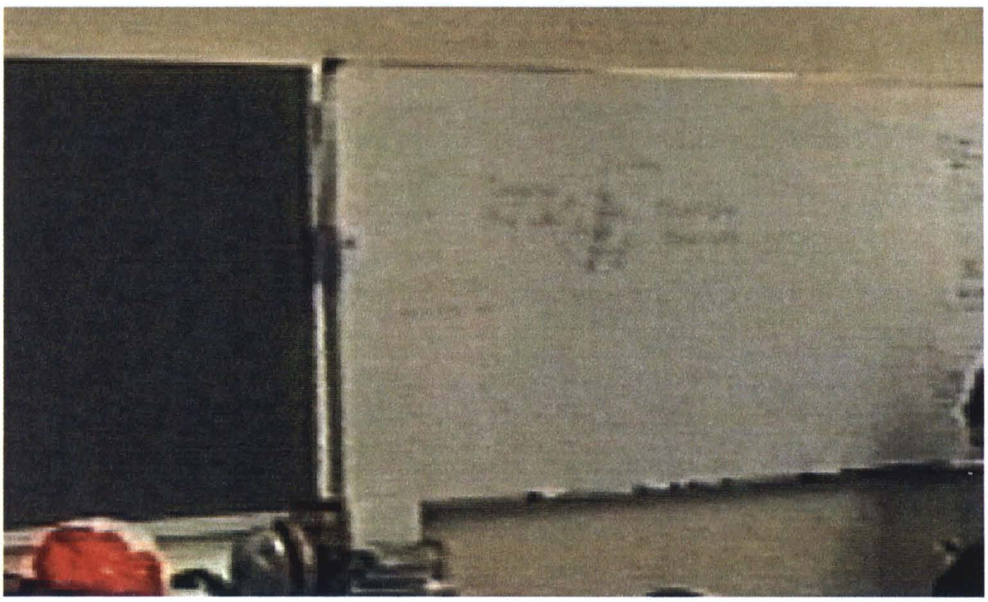
The worksheet redrawn on the board – lesson 2

The string model held by the researcher – lesson 3

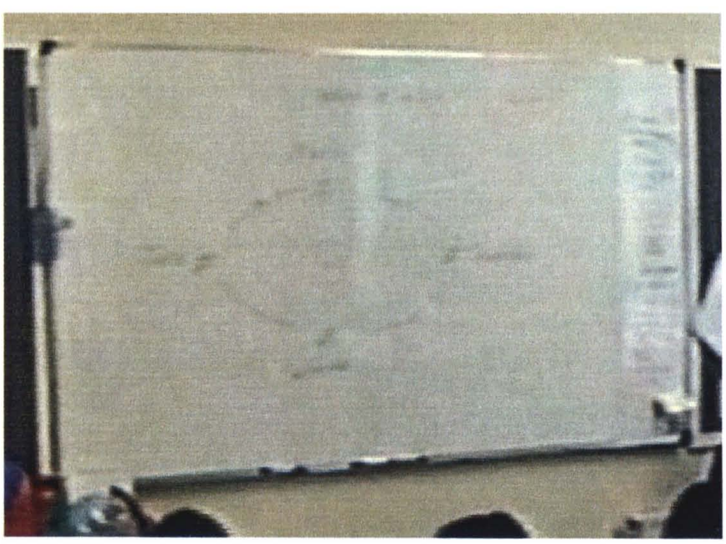


The wall poster on the board – lesson 4

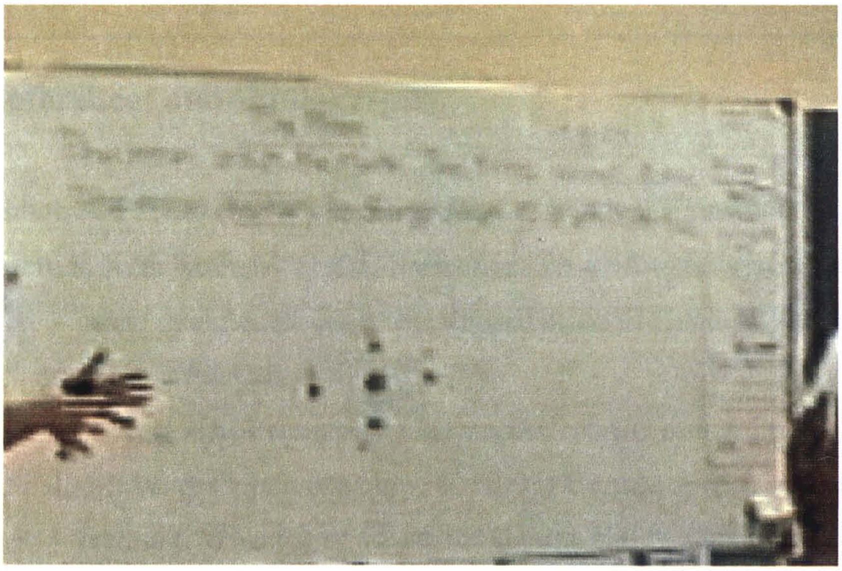
The relative size of the Sun, Earth and Moon demonstration – lesson 7



Board diagram of day and night – lesson 7



Board diagram of the seasons – lesson 8



Board diagram of the phases of the Moon – lesson 12

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